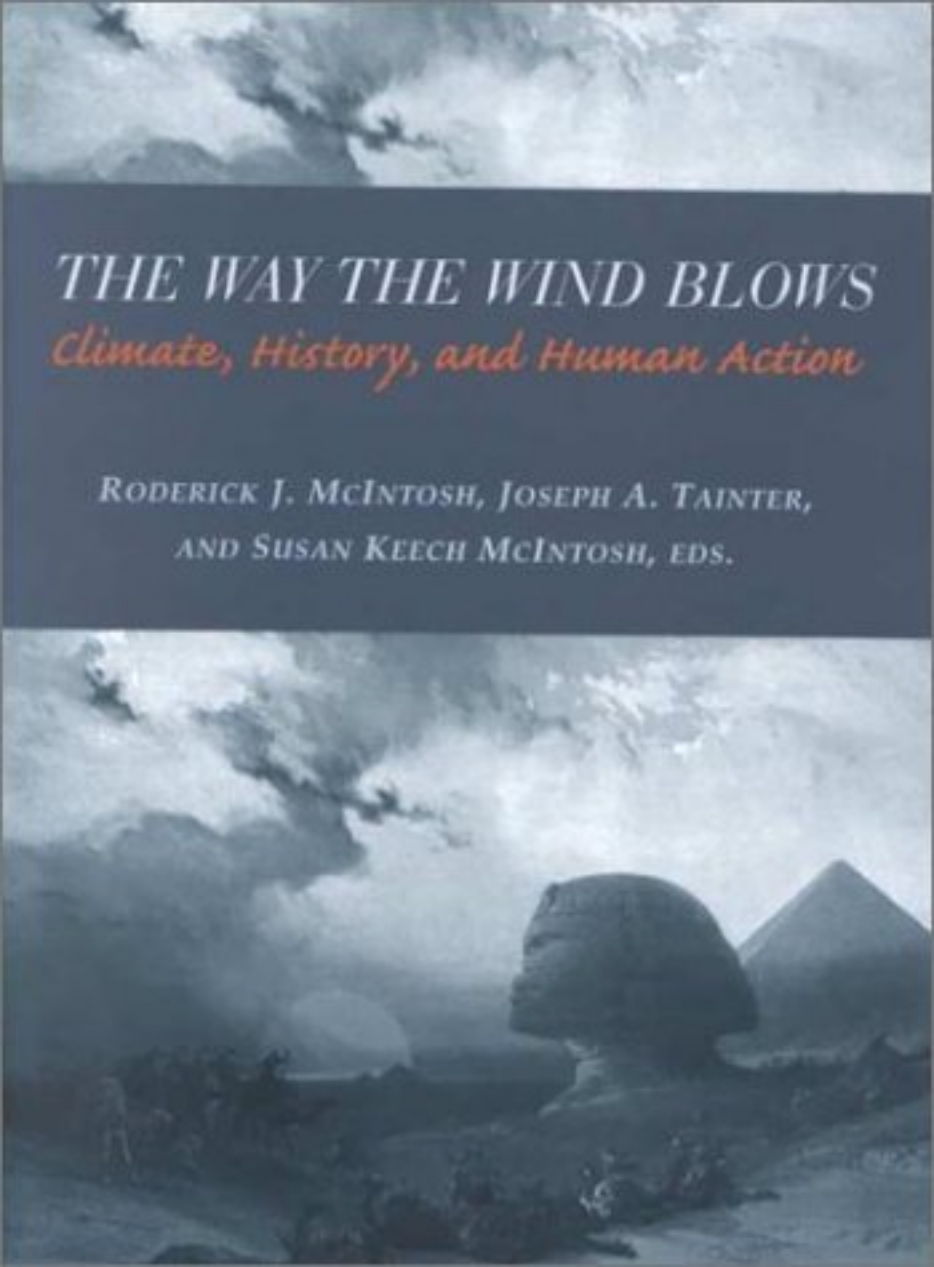
THE WAY THE WIND BLOWS
Climate, History, and Human Action
Roderick J. McIntosh, Joseph A. Tainter,
and Susan Keech McIntosh, eds.

The Way the Wind Blows

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The Way the Wind Blows: Climate, History, and Human Action

Edited by

Roderick J. McIntosh

Joseph A. Tainter

Susan Keech McIntosh

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For Anne and Phil, and Patrick and Lillian
—JAT

For our parents
—RJM and SKM

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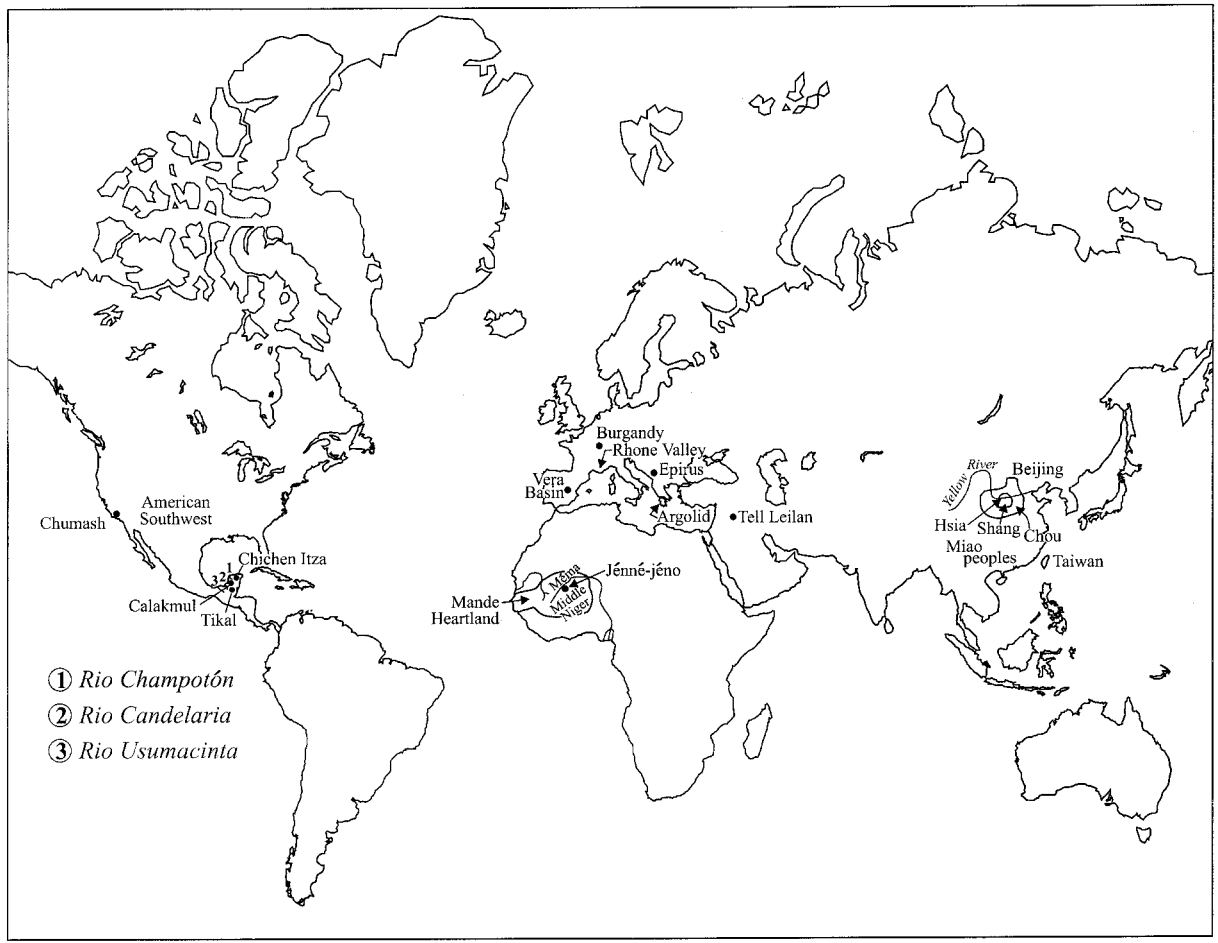

Major sites and areas mentioned in the text.

Chapter 1

Climate, History, and Human Action

Roderick J. McIntosh, Joseph A. Tainter, and Susan Keech McIntosh

> Winter Storms Worst Ever! . . . Killer weather triggers fear of new Ice Age! . . . Savage storms, ferocious floods and brutal blizzards will ravage the entire nation for six nightmarish months—triggering fear and panic on a scale we've never seen before!
>
> *R. E. Smythe*

Within only a few years, concern over the climate has evolved from the province of specialists and unheeded doomsayers to the front page, top banner, of the tabloid press (fig. 1.1). Climatology has emerged into public consciousness to the point where it is routinely discussed not only in the mainstream media but also in publications that typically report alien abductions, reproductive aberrations, and biblical portents. Yet even within these latter publications, anomalous weather and climate are now presented less as freaks of nature than as emerging norms.

As amusing or annoying as tabloid journalism may be, it is quite unnecessary. The real story of climate change and its human consequences stands on its own merits among the great dramas of human history. Yet the historical relationship of humanity to climate is a story that remains substantially untold. This book begins that narrative. It reports the findings of a conference convened to bridge the gap between climatology and the human sciences in the study of this most important matter and to bring the history of human responses to climate to the international debate on climate change.

History and the Social Construction of Environmental Change

The Global Change Workshop

As humanity contemplates the convergence of rising population, increasing poverty, environmental transformation, and a changing climate, we discern two parallel developments. The first is well known and was always

BIBLE and Meteorologists warn Pollution Cloud, Comet of Doom & El Niño will make...
Sun
$1.29/$1.39CANADA October 21, 1997
WINTER STORMS WORST EVER!
HAILSTONES batter North West
BLIZZARDS cripple air travel
BLACKOUTS paralyze North East
BLINDING FOG shuts down central U.S.
SLEET BLITZ freezes Mid West
SNOW blasts South
EARTHQUAKES tear up West Coast
FLOODS swamp South West
HURRICANES pound East Coast
Killer weather triggers fear of new Ice Age
WILD BEAR SAVES BABY IN ZOO FALL

Figure 1.1.
Weather and climate in the public arena.
Reproduced by permission.

predictable. It is the tendency to declare that the problems that so many foretell are not genuine, or that if they are genuine they are not serious, or that if they prove both genuine and serious, scarcity will spur the innovation necessary to resolve them. Whatever the case, there is no need for either alarm or remedial action: markets will correct all problems (see, e.g., Simon 1981). The second trend is more subtle but evident to many observers of environmental change. Increasingly, we realize that environmental problems do not exist on an independent plane in the biophysical world. A phenomenon becomes a problem only when people perceive it to be, and this only occurs when society cannot adjust to it. Environmental problems are fundamentally

human issues. They can only be understood or addressed through comprehending their social, cultural, political, and economic contexts.

The adherents of the first view—that distress automatically brings forth its own solutions—hold to a set of mostly unexamined assumptions: humans behave in ways that economists consider rational, we do so at all social scales from the individual to the international community, and we have always done so. Those who recognize the second perspective believe somewhat differently: that notwithstanding market forces, a phenomenon as great as the earth's climate, and human responses to it, must be understood and anticipated through a combination of social and biophysical research. Yet most people who subscribe to either perspective would be unable to answer a simple but significant question: how have people historically responded to changes in climate and other environmental variables? The vast experience of human history has been absent from public discussions of climate change and from most professional discourse. By ignoring the great laboratory of millennia of responses to environmental change, we condemn ourselves to reinventing a very complex wheel in the face of one of humanity's greatest challenges.

To address these matters, the conference "Global Change in History and Prehistory" was convened at the Woodlands Conference Center near Houston, Texas, from 2 to 6 September 1995.[1] Participants (all of whom contributed to this volume) were selected for their research and professional accomplishments, with the aim of providing broad geographical, cultural, and temporal coverage. They are from four continents—Africa, Asia, Europe, and North America—and their research covers the spectrum of human experience from the hunter-gatherers of California to the most enduring civilization, China. To ensure that the contributions would be of high quality, the conference employed a format often used at the School of American Research. Conference papers were prepared in advance. Each was then critiqued by two other participants and discussed by the group. At the conclusion of the conference, syntheses of the papers and discussions were presented to an open meeting of the faculty of Rice University in order to gauge the reactions of an audience of primarily biophysical scientists. The papers appearing here reflect these discussions and critiques, as well as conventional peer review through Columbia University Press.

Expanding Our Understanding of Climate Change

It is the predilection of the Western cultural tradition that we tend to view environmental problems through engineering lenses, as matters external to ourselves, amenable to rational, reductionist analyses and solvable by manipulating parts, one at a time, on the basis of biophysical science. This perspective inevitably views such things as energy, pollution, biodiversity, and land degradation as primarily environmental problems that have a social component. This in turn leads inevitably to the assumption that

addressing an environmental problem will automatically meet the needs of the social component. Constraints are presumed to flow from the environment to people, with the social component a fully dependent variable. By marginalizing the social dimensions of environmental variation, solutions can be engineered with confidence that they are appropriate to the needs of people, if not immediately, then surely in the long run.

Reflecting this view, the Intergovernmental Panel on Climate Change (IPCC) devoted an entire volume of its 1995 report to the economic and social dimensions of climate change (Bruce, Lee, and Haites 1996). It is a remarkable compilation, addressing pressing issues such as adaptation and response options (Banuri et al. 1996; Pearce et al. 1996; Jepma et al. 1996; Hourcade, Richels et al. 1996; Fisher et al. 1996); equity (Banuri et al. 1996; Arrow, Cline et al. 1996); decision-making frameworks (Arrow, Parikh et al. 1996); and economic considerations (Hourcade, Richels et al. 1996; Hourcade, Halsnaes et al. 1996; Fisher et al. 1996). Yet while that work is surely the most significant volume on the topic, its contents are far from comprehensive. Indeed they display some marked biases that limit understanding of the range of human responses to climate. These biases manifest themselves in issues of scaling, in overreliance on economic theory, in little consideration for history, and in misplaced concreteness. We comment briefly on each.

"Scaling" refers to the level at which humans respond to climate and environmental change. As befits an organization chartered by the United Nations, IPCC considers adaptation and responses primarily at the level of nations and, within nations, at the level of cities. Discussions of equity, for example, usually turn on relations of developed nations to those in transition. Adaptation is considered in terms of responses that nations might undertake (or, in some cases, what to do when entire nations become submerged), such as steps to protect coastlines and low-lying cities. These matters are important, yet they are not the considerations of most people who are affected by environmental change. The major part of humanity's adaptation will come at the local level, at a community or regional scale, and among people who know nothing of such concepts as international or intergenerational equity. As Carole Crumley's paper in this volume makes clear, environmental responses at this level are based on knowledge of which national governments are typically unaware. Equity solutions that are not based on considerations at the appropriate scale will merely shift the inequities, not resolve them.

Neoclassical economics, in its simplest form, assumes that values can routinely be monetized and that losses can always be compensated fiscally. This view has found favor among policy makers. Much contemporary policy derives from the assumptions that (a) the value of a good is reflected in willingness to pay for it and (b) the extent of damage (e.g., to subsistence production systems) is reflected in willingness to accept compensation. Yet the great majority of people who have lived since our species emerged and prior to the industrial era would find such notions incomprehensible. People give symbolic meaning to their world and can rarely equate those mean-

ings to economic values; it does not occur to most people even to think in such terms. Alaskan natives studied by one of us (Tainter 1997), for example, state that they cannot be compensated monetarily when timber harvesting causes a decline in the availability of traditional foods. These foods have meanings in social and ceremonial life for which there is no substitute. If natives receive money for their loss, they are still worse off. Even for industrial societies economic reasoning can be carried too far. Agriculture, for example, represents only 3 percent of the United States economy, thus by economic reasoning the total loss of our agriculture would amount to only a moderate recession (Ekins 1996:139).

In their disdain for history, policy makers tend to look only to the recent past to understand the sources of problems (Watt 1992; Tainter 1995). Longer-term views are rarely adopted. Perhaps one benefit of climate change is that it is forcing policy makers to extend the temporal range of their thinking, into both the past and the future. Modern observations on both human behavior and environmental variation span too brief a time to capture the full range of their variation or of their interaction. It is sobering to learn, for example, that atmospheric lead pollution reached a level in the first century B.C. that was not seen again until the industrial revolution (Hong et al. 1994). Environmental variation and human responses change according to timescales that stretch from decades to millennia. The characteristics of a particular moment—such as today—cannot be understood except in the context of the long progression of past structures and processes that have conditioned it. A good understanding of human responses to climate change must come from a combination of contemporary instrumental observations, ethnography and human geography, paleoenvironmental and paleoclimatic modeling, history, and archaeology.

Misplaced concreteness arises from our inclination to see every problem as responding to engineering and to devise technical solutions accordingly. Solutions, in the technical way of thinking, must be tangible, both to accommodate this inclination and to show funding agencies what has been accomplished. Yet subsistence producers like many of the groups discussed in this volume survive only partly through technology. They survive also by networks of social relations through which they gain access to extra labor, food, and other resources, and by cosmologies and myths that preserve an unwritten record of past climatic episodes, successful responses to them, and proper relations to the environment. (We use the term "social memory," a concept described later in this article, to designate this symbolic and cosmological component of human adaptation.)

The social component of adaptation is pervasive and fundamental yet largely invisible to observers outside a community (one cannot show a social network to a funding agency). Yet large-scale technological problem solving often has the potential to disrupt such networks, leaving local populations without a major part of their survival kit. In the area of the inland delta of the Niger River of Mali, for example, a diverse set of ethnic groups coexists by specializing in subsistence production and exchanging labor at the appropriate

times in each group's peak labor period (McIntosh and McIntosh 1980; McIntosh 1993). This delicately balanced system of roles and reciprocities allows many ethnic groups to coexist, in stark contrast to many places where ethnic groups have great difficulty coexisting. Yet at one time, under colonial rule, the Office du Niger planned to switch much of the region to intensive rice and cotton production. Converting this diverse and richly networked production system to monocultures would have undermined the reciprocal social obligations by which the people of the area survive. Cooperators would have been turned into competitors.

One of the most appealing aspects of indigenous systems of production, such as that of the Middle Niger, is that they are developed at the local level and are easily sustained at that level. They impose only minimal costs to the larger society. One fault of a scheme such as that of the Office du Niger is that, beyond destroying a self-regulating local network, it would have replaced it with one requiring continuous infusions of external capital, fuel, and expertise. Though such systems can be quite productive, over the long term they are inherently less sustainable (Tainter 1996a and this volume; Allen, Tainter, and Hoekstra 1999).

We do not suggest that the macrosocietal technological-economic approach exemplified in the work of the IPCC is inherently wrong. Certainly it has achieved many successes and should be used where it is appropriate. Its problem is primarily that it is incomplete. It fails to reflect much of the human experience. The contributors to this volume offer a very different perspective on climate and environmental change. In this view, humanity is central to environmental issues, not in the sense that nature is secondary but in the more profound sense that human cognition and adaptability transform many statements about climate and environment from certain to relative. This transformation includes fundamental ecological concepts such as disturbance (Tainter and Tainter 1996a), land-management concepts such as degradation (van der Leeuw 1998 and this volume), and ecological certainties such as the desirability of landscape diversity and complex food webs (Allen, Tainter, and Hoekstra 1999). Some points to emerge from the articles in this volume follow.

1. Humanity interacts not directly with nature but with its perceptions of nature, and it acts on those perceptions.
2. A major portion of any human response to climate or other environmental change is through behaviors that are intangible: changes in social networks, in relations of reciprocity, or in the cosmology that defines the place of humanity in nature.
3. Given our extraordinary adaptability, environmental transformations that might be catastrophic for other species may not be for humans or may even present us with significant new opportunities. As van der Leeuw points out in the concluding essay, even changes that many experts would consider to be environmental degradations may, for a

local human population, merely constitute changes in the opportunity spectrum.

4. To a human population, an environmental crisis is primarily a matter of the social realm, implying a failure of adaptation. The truly interesting questions in such cases involve not just meeting the biophysical challenge but also understanding why human problem solving seems on critical occasions to become ineffective (Tainter 1988 and this volume).

Readers of this volume will sample some of the range of human responses to climate and environmental change. While far from exhaustive, the book includes a broader range of responses than has been assembled in any other source. The responses are to a great degree vague, relative, flexible, and intangible. Biophysical scientists may find that they miss the certainty and concreteness that characterizes their fields. But the less palpable nature of human behavior is, fortunately or unfortunately, an inherent aspect of social science, and it must be grasped, for humanity is central to environmental change. Ecosystems care not about climate, biodiversity, nutrient leakages, or whether they lose species. Whatever happens, they adjust automatically. It is only people who care about these things, and that concern is what justifies and sustains the research of both biophysical and social scientists.

Bridging the Social and Biophysical Sciences

In 1986 Rhodes Fairbridge coined the term "break-through recognition" to describe his prediction of an imminent revolution in our understanding of the causes and rhythms of climate change: solar radiation and the earth's orbital eccentricities (1986:143). Advances in biophysical research have largely substantiated this prediction (although we are certainly far from total revelation of internal and external forcing mechanisms). This can been seen in the far denser texture of climate mechanism descriptions in volumes 1 and 2 of the 1995 reports of the IPCC (Houghton et al. 1996; Watson et al. 1996)—as compared, for example, even to the IPCC's first assessment report of 1990 and the supplements of 1992 and 1994 (Houg, Callander, and Varney 1992; Houghton, Jenkins, and Ephr 1990; Houghton et al. 1994)—and in the rapid improvement of modeling based on increasing spatial resolution, knowledge of radiative forcing mechanisms, and appreciation of global linkages and causation. The historical sciences may also be on the verge of a breakthrough in our recognition of how societies have responded to climate change. Yet historical scientists and biophysical scientists are not fully communicating to each other the implications of these advances in knowledge. One of the reviewers of this book in manuscript remarked that there seems to be a growing gap between biophysical and historical scientists, a "'dialogue of the deaf,' in which each camp pursues its own agenda almost oblivious to the concerns of the other."

This book is one of a few to bridge that gap. In the global change workshop of 1995, participants spoke optimistically of an alliance between the biophysical and historical sciences to understand mesoscale dynamics (a concept to which we return shortly). Half the workshop participants were selected because they had active research and publication records in the biophysical and paleoclimate sciences (Dunbar, Dean, Gunn, Hassan, McIntosh, and van der Leeuw). The participants discussed three compelling reasons why researchers in the biophysical sciences should take an interest in the social side of climate change.

First, as noted, environmental problems do not exist on an independent biophysical plane: environmental problems are fundamentally human issues. Over the last ten years, Congress and ultimately the taxpayers have increased enormously the climate research budgets of the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), the Departments of Energy and Defense, and the National Oceanic and Atmospheric Administration (NOAA) because of a general disquietude about issues such as greenhouse gases, ozone depletion, climate pulses such as the El Niño–Southern Oscillation (ENSO), and anthropogenic alterations such as tropical deforestation. Those funding research are not abstractly interested in climate gone awry; rather, they seek prediction of the human consequences of climate and guidance on policies.

Another reason for greater cooperation between the so-called hard and soft sciences is that paleoclimatologists need ways to expand their databases beyond the instrumental record that covers, at most, one or two centuries in most parts of the world. Many proxy measures of climate change now used by biophysical scientists, such as sunspot observations, parameteorological weather and biota observations (e.g., harvest timing, bird migrations, or personal diaries), river flow and flood events, lake sediments, pack rat middens, or pollen profiles are either primarily social phenomena or demonstrably affected by the ubiquitous human modifications of landscapes. Human modification has been more extensive and is far older than even archaeologists have hitherto appreciated. "The earth transformed" (Goudie and Viles 1997) must be a major research focus for future attempts to understand systematically the effects of human agency and history on the physical, biological, and social patterns and interactive processes of global ecology. Biophysical scientists interested in proxy data will want to maintain lines of communication with historians or anthropologists who can help with the critical assessment of the evidence.

It is important to remember that paleoclimatic proxy data share the same problem that affects all such data: the fallacy of affirming the consequent. In complex systems, causes cannot always be derived from observing the consequences. In nonlinear systems in which human responses to the physical landscape provide the initial conditions and continuous (endogenic) adjustments, the researcher must observe the whole historical trajectory in order to see links among subsystems. A shallow approach to history, either by bio-

physical scientists or by environmental policy makers, betrays deeply flawed habits of causal reasoning.[2]

One final factor should foster improved communication among the sciences. It is clear from the December 1997 Kyoto negotiations and their aftermath (if it was not clear before) that politics and economics weigh more heavily than science in the consideration of climate change. The immediacy of quarterly balance sheets (for industrialists), unemployment levels (for politicians in industrialized nations), and poverty (for the leaders of much of the world) commands attention much more readily than the threat that someday things may go quite wrong. It has always been so. Humans have rarely, if ever, prepared for far-off eventualities, particularly if such preparation requires consensus and sacrifice. We are a species that adapts to near-term conditions. It will be advantageous to biophysical scientists to recognize this fact, if only to reduce their frustration at self-serving behavior and pseudoscience. It is also worthwhile to understand that advocacy by scientists reduces them in some policy makers' minds to just another interest group.

The Battle to Control Reality

There is a need in the public arena to expose so-called science presented by economic and political interests only to maintain a status quo from which they benefit (Gelbspan 1997). In 1987, for example, two Russian scientists, M. I. Budyko and Yu. A. Izrael, published an early analysis of the likely consequences of global warming (Budyko and Izrael 1991). Their research is a thick volume of equations, charts, maps, and conclusions, presented with none of the uncertainty that pervades climatology elsewhere (Tainter 1994). Global warming, according to this analysis, will conveniently favor the northern parts of the former Soviet Union, bringing greater precipitation, less sea ice, higher primary production, longer growing seasons, greater agricultural production, and increased economic opportunities. The entire argument (whether intended or not) seems to legitimize the uncontrolled use of fossil fuels that characterized Soviet-bloc economies.

Sums of money and even careers can be made by catering to the common human tendency not to appreciate bad news. There is no shortage of writers ready to relieve any anxiety about present or future conditions. John Cochener, writing in the influential trade journal *Hart's Natural Gas Focus*, penned an article titled "The Iceman Cometh?" (1995), a clever antithesis to the prospect of lower gas consumption in a warmer world. Cochener predicted a cool winter, even cooler times to 2001, and thereafter ever-greater winter demand for natural gas because of increased volcanic aerosols. The reasoning underlying these predictions is a virtuoso orchestration of the effects of six converging cycles, which peak together for the first time in three hundred years. These include ENSO (depressed), the 11-year sunspot, 22-year magnetic, 179-year retrograde solar motion, 6-year Chandler earth wobble, and 10-year volcanic cycles. We are moved by this symphony of parallel sine waves and

nested cycles both to wonder how anyone could fault legitimate climatology for its uncertainty and to hope that no one bought gas futures based on Chandler's predictions. Recent winters in the United States have been notably mild.

It is increasingly difficult for concerned citizens or policy makers to distinguish legitimate, peer-reviewed science from that which panders to special interests. Journalists amplify this confusion by their tendency to present all policy disputes as tests of virtual combat between opposing champions. Even if nearly all scientists agree on a matter, journalists will always find one who doesn't (or perhaps not even a scientist) and then present the dispute as a contest between views of equal merit. It is a distressing tendency that sadly we cannot correct. What Gelbspan calls the "battle for control of reality" (1997:55–56) pits science in self-interest (as in these examples) against science intended for the public interest (e.g., Mannion 1991; Strzepek and Smith 1995; Somerville 1996; Karl, Nicholls, and Gregory 1997). A few months before this text was written (April 1998), the Clinton Administration invited local television weather forecasters to a White House briefing on climate change. It was of course a media event, part of the battle to control reality. The subsequent interviews and presentations to home audiences quite predictably featured not the evidence but the uncertainty and the dispute. Journalists, however fine their intentions, will always use scientific issues to serve their own interests.

Toward Building a Common Language

As Sander van der Leeuw discussed at the 1995 conference that produced this book, there have been some six hundred years of divide in the Western intellectual tradition between the human and biophysical sciences (see also van der Leeuw 1998). The biophysical sciences emerged from a Newtonian tradition that celebrates replicability, reductionism, and de-emphasis of positive feedback between humans and the rest of the environment. In this last view, humans are sometimes seen as alien to and even parasitical on the physical environment. In the extreme representation, the role of humans is not to function as stewards but to conquer, tame, and subdue the environment (Beinart and Coates 1995). Conversely, some historians and ethnographers have looked at environment as mere backdrop and at climate change as so slow, so vast in scale, as to be virtually irrelevant.

We should no longer tolerate this division. A unifying premise of the 1995 global change workshop and this volume is that all mesoscale dynamics—the bridge of time and affected space between weather and very long term climate—have had a significant human intrusion for at least the past six or so millennia, if not for tens of millennia. Mesoscale climate patterns are expressed over times ranging from annual, through decadal and centennial, to, at the extreme, millennial. As historical and archaeological research on past landscapes improves, we are becoming aware of the degree of recursive

human influence on local and even regional climates. For this and for the several reasons given above, it will benefit both sides of C. P. Snow's "two cultures" (1993) to develop a common language to appreciate fully the history and prehistory embedded in human responses to climate and indeed in climate itself. We seek ways to cast our nets more broadly over the ocean of climate change and human response data that lie waiting to be revealed. Some data are of a biophysical nature, while some may best be tackled by the historical sciences. A premise built into the social-memory focus of many of the essays in this volume is that data lie hidden but discoverable in humanity's deep symbolic past. As Fekri Hassan noted during the workshop, "We are endangered by history, by our shallow approach to the past. . . . And, in fact, at a time of global interactions, at a time when we need all the information that has been available to humans over time, we need . . . to access this diversity of stored information as a way to deal with various present crises."

The work of crafting a common language that permitted the archaeologists, historians, and paleoclimatologists at the workshop to communicate meaningfully proved arduous but rewarding. In the course of extensive discussions that began within minutes of the opening session, we made significant progress, with the result that the frequency of "ships in the night" conversational encounters dropped noticeably. Peter Galison (1997) has discussed at length the vital role that the use of "trading languages" play in permitting interaction in the contact zone between different science subcultures. Where different cultures (whether scientific or ethnographic) meet, they can coordinate their very different symbolic approaches to the world by creating local senses of the terms that speakers of both parent languages recognize as important to interaction or trade. Galison calls the cultural arena within which these interactions take place "the trading zone" (1997:46), an intermediate domain in which procedures can be coordinated locally even where broader meanings clash.

Although we present here the terms and definitions that emerged from our trading-zone discussions, readers may find it instructive to have a sense of how debate proceeded, what terms and meanings were the most hotly contested, and why.

Variability—defining it, understanding it, describing it—was an issue that arose with the very first presentation at the conference (Dunbar's climate paper), and it dogged us throughout, ultimately resulting in a number of concepts (e.g., mode shift, threshold, cumulative deviation) that all parties found useful. The archaeologists rejected any suggestion that variability was a neutral property of paleoclimatic data sets, the description of which involved primarily the application of appropriate statistics. Statistics such as mean, mode, and variance can all obscure very different patterns of variability, for example, periodic low-level fluctuations as compared to rare extreme events. The archaeologists' rallying cry leading the discussion charge was "Unpack variability!" This involved considerations far beyond dissecting the various ways that statistics are able to homogenize heterogeneous data. Most significantly,

it involved explicit recognition that, for any discussion of the human consequences of climate change, the nature of climate variation cannot be separated from human perceptions of it. If human consequences are what interest us, then the climate variables and scales of measurement selected for analysis must be relevant to the human perception and experience of climate. Widely used terms such as "stability," "change," "variability," "normal," or "degradation" only have meaning within defined scales of analysis. Shift the scale, and the meanings change. Which scale is most appropriate, then, for the investigation of questions involving human response and climate change?

Conference participants considered Jeff Dean's proposal that variability could be divided into two frequency bands—low (> generational) and high (< generational)—and that low-frequency variability was most likely to provoke significant changes in human response, because societies will normally be prepared for and well adapted to even the most extreme conditions that occur at high frequencies. Although there was some discussion about how long a generation should be considered to last (twenty-five years? forty years?), the focal issue seemed to be the span of living memory, which normally transcended a generation, because of the presence of elders. Fekri Hassan proposed sixty to one hundred years as the relevant timescale at which societies effectively evaluate variation and the chances of bad events recurring. By this reasoning, variation at decadal and century scales is highly relevant, and data at this level of precision should be pursued whenever possible.

As for the appropriate geographical scale of analysis, the archaeologists unanimously agreed that the local region, corresponding to the likely catchment area of the resources used by a society, is often the most appropriate scale (the region will vary with the scale and mobility of the societies in question). Here, discussion highlighted the very different usages of the term "region" by archaeologists in contrast to paleoclimatologists, who tend to divide the globe up into vast regions, for example, the global monsoon belt.

With regard to both time and geographic scales, the appropriate level of investigation thus concerns what we have termed "mesoscale dynamics" (borrowing from the parent language of climatology, where it refers to the bridge between weather and long-term climate). Geographically, our interests lie between the village-level studies of ethnography and the continental-global models of climate; temporally, they lie between the daily scale of weather and the paleoclimate records that stretch over tens of thousands of years. We have staked out a terrain that bears a certain resemblance to Galison's "mesoscopic history" (1997:61), intermediate between universalizing macrohistory and nominalistic microhistory. Conference participants noted that in this novel terrain, historical and scientific approaches need to join forces and methodologies; the goal is to uncover the broad principles that govern human response to climate change over a wide range of historical cases, each of which will have to be examined individually to tease apart how differences in subsistence systems, social organization, cultural values,

and historical experience are implicated in particular responses. We are especially interested to learn what factors contribute to the continuity and resilience of human systems in the face of repeated and sometimes drastic climate change. Conversely, we need to know what factors put societies most at risk when faced with climate disturbance.

A wide range of factors relevant to the question of resilience (defined as the ability of a system to maintain its structure in the face of disturbance and to absorb and utilize change) was identified during conference discussions. These included subsistence mode and resource diversity, scale and organizational structure of society, and the nature of cultural strategies for gathering, storing, evaluating, and acting on information about environmental variability. A great deal of discussion at the workshop focused on the interrelations among elements of organizational structure and information flows. But substantial terminological negotiations among the archaeologists over notions of "complex" and "simple" societies were a recurring feature of the discussion.

In particular, the notion that so-called complex society implies hierarchical organization was critiqued on several occasions, in particular the heavy nineteenth-century evolutionist baggage that the term carries. Complex societies generally share the characteristics of increased scale, specialization, and integration of their members. Different organizational formats, however, can accommodate these characteristics: for example, horizontal integration of multiple overlapping social lattices, each of which may have a different center (heterarchy), as well as vertical integration, in which the networks of power and information within society are streamlined by ranking the various centers, creating a hierarchy. Once both heterarchy and hierarchy were in active play in the discussion, the tendency of participants to polarize them was noticeable. Hierarchies such as kingdoms were initially characterized as capable of quick responses to change thanks to their streamlined information networks involving relatively few decision makers. The downside of hierarchies is their bureaucratic rigidity. Heterarchies, such as tribal councils, while potentially agonizingly slow to make decisions, because everyone has a voice in the process, have the advantage that information is not lost in a streamlining process. And information, we all agreed, was of signal importance in the ability to make sound judgments in the face of a changing environment. (These points are discussed further in a later section of this overview.)

As discussion progressed, however, it became clear that hierarchy and heterarchy were far from dichotomous. Local heterarchical substructures of ritual specialists concerned with weather and its management were a persistent feature of the Chinese state, for example. Such groups counterbalance the effects of the institutionalization of information gathering and storage in state systems, where certain types of information are privileged by decision makers and other types are overlooked. Although the total amount of information carried in a state system is vast, the sources and types of information

relevant to local conditions may be substantially reduced. Heterarchical subsystems with local response domains can counteract the tendency toward reduced responsiveness and flexibility in hierarchical systems. It thus becomes important to evaluate social organization within a hierarchy-heterarchy matrix, noting the topology of both within a society. This exemplifies a broader classificatory issue that was discussed at some length: the need for ongoing vigilance regarding the utility of the discrete, bounded categories (stable/unstable, wet/dry, complex/simple) to which we naturally incline. There may be cases where looking at the nature of variation across boundaries, rather than within them, may be more productive.

Beyond the issue of how information is gathered and stored, there are also considerations of how it is retrieved and acted on. Salient factors include the role of orality versus literacy in the society, the location of information gatekeepers, and their relationship to decision makers. Cultural and political factors may constrain or proscribe how elites respond to crisis or change, and limit their ability to innovate. The role of cultural schemata (a term contributed by Fekri Hassan) that order knowledge and filter information in structured ways particular to each culture was discussed at great length as we sought to develop ideas and terminology appropriate to the concept of social memory. The second half of this chapter elaborates on these concepts.

In this volume the reader will encounter concepts of particular utility to biophysical scientists seeking to understand how historians, or archaeologists, or historical sociologists look at the deep past of historical global ecology or the interactive conditions of social, biological, and physical conditions of the earth system. The reader will see how tenure at the Santa Fe Institute profoundly influenced some of the contributors (especially Dean). Some chapters explore the spontaneous order and self-organization (Kauffman 1995) of human communities over the dynamic physical environment.

A concept implicit in many chapters is that human, other biological, and physical systems form complex nests of hierarchically-organized ecosystems (Allen and Starr 1982; Allen and Hoekstra 1992; Ahl and Allen 1996; Allen, Tainter, and Hoekstra 1999; O'Neill et al. 1986). The human presence (including hierarchies of settlements and regional control bureaucracies) is not simply overlaid onto the ecosystem but integral to it. Concepts such as self-organization and hierarchically organized ecosystems make it plain that the biophysical and (human) historical are but two sides of one and the same cloth. Because of this, it makes sense now to look in more detail at four conceptual aspects of the biophysical side of this cloth: *landscape*, *variability*, *modes and mode shifts*, and *modeling and simulations*.

Landscape. The idea that the biophysical world (including humans) is a nested, hierarchical ecosystem is central to this volume's concept of landscape (see, e.g., Crumley 1994b; Crumley and Marquardt 1987). A landscape comprises all physical, biological, and cultural phenomena interacting within a region. Some portions of a landscape will manifest themselves as physical residues of antecedent landscapes within a local developmental tra-

jectory (see van der Leeuw 1998 and his contribution to this volume), residues that include evidence of human action on the physical environment. Hence biophysical scientists (geomorphologists, paleobotanists, etc.) and historical scientists (archaeologists, paleoethnobotanists, etc.) can study traces of interactions at different scales among the elements of landscape. Some descriptions of hierarchically organized ecosystems focus primarily on the biophysical world either devoid of humans or incorporating them occasionally. In this volume, human institutions and behaviors (which can themselves be hierarchically organized) are nested within the biophysical. The human is explicitly *not* superimposed on the biophysical.

Cultural landscapes show signs of the cognitive organization of environmental elements, aligned according to human functions of recall, patterns of behavior, and compressed models (schemata; see below) of regularities that human communities employ in their conceptualization of interacting physical and social elements. These are the aspects of landscape that define the dimensions of social memory. Interfaces are particularly important: human societies often thrive at the divide between two or more landscapes. "We are, after all," Carole Crumley reminded us, "an ecotonal species."

The study of landscape begins by unpacking interactions at a variety of scales. The concept of the landscape derives from the idea of coevolutionary interaction (all elements mutually influence each other over time), and in any subject so complex, the devil is always in the details. Climate variability is among the most pertinent issues in defining the regional character of a landscape.

Variability. Critics of climate change research assert that uncertainty about variability is the soft underbelly of the consensus warnings of the scientific world (e.g., Pollock 1997; Bates 1997; *The Economist* 1997a, 1997b; see Gelbspan 1997). Not surprisingly, much of the volume on climate process (report of working group 1) of the 1995 IPCC report is devoted to observation and assessment of variability (Houghton et al. 1996:133–192, 407–516). An appreciation of the biophysical impacts of climate variability permeates the entire second IPCC volume, *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses* (Watson et al. 1996).

The participants in the workshop identified three dimensions of climate variability that are especially pertinent to our shared vision of landscape: (1) *variation*, or changes in the status of a system (in this case, climate) that fall within a range that is tolerable without requiring major adjustments in adaptation or causing surprise or risk (as defined below); (2) *shape of climate variability*, or variability modeled geometrically or statistically to abstract patterns from observations; and (3) *cumulative deviations*, a statistical method for measuring long-term trends, a measurement of a time series that is sensitive both to accumulated quantities and changes in trend. Perhaps the most promising field of recent paleoclimate research deals with interannual-, decadal-, and century-scale variability. It is at these levels of mesoscale

dynamics that the historical and the biophysical sciences can most immediately form an alliance for research and public education. It is here that the biophysical scientists' need for historical data is most acute.

The instrumental record cannot capture the full range of past variability: it goes beyond one hundred years in relatively few parts of the globe. Consequently, there has been a tendency to concentrate on the shape of variability (and on the causal processes illustrated thereby), represented by the very high quality (but relatively recent) data recovered by, for example, expensive satellite platforms. The proxy data of the historical sciences (e.g., Hsu in this volume) are badly needed to balance that bias. Further, many observers suspect that the climate patterns of the modern period are anomalous. Specifically, there is less absolute variability in the recent record than we can infer from other data sources for most of the Pleistocene-Holocene, and it may be that recent, short-term patterns (including warming) are simply parts of poorly understood longer-scale cycles. Moreover, some suspect that human modification (in the form of imperfectly understood mechanisms such as altered levels of greenhouse gases, stratospheric ozone depletion, smog constituents, and other anthropogenic manipulations of which we are only now becoming aware) have caused unique patterns not seen before the industrial revolution. This is, for example, one of the hypotheses being investigated as a reason for the intensity and persistence of the Sahel drought, which began in 1968 and is still ongoing (Climatic Research Unit 1998).

All this underscores the need for biophysical and historical scientists to develop a common language in order to insert more historical data and more discussion of human responses into our understanding of climate change. In this volume, the reader will find discussions of the climate record along several dimensions. The first is time (range, periodicity, cyclical or anomalous jolts, and metastable mode shifts). The second is space, for the unifying landscape concept is, after all, regional in definition. Variability in space is expressed in terms of local effects, regionality, interregionality, teleconnections affecting widely separated regions of the globe, global forcing phenomena, and the assessment of so-called global episodes (such as the Little Ice Age) that may be evident in some regions but not in neighboring ones. A third dimension of variability, related to the first two, is scale: chronological (diurnal, intraannual, interannual, decadal, century or 10^2-year, millennial or 10^3-year, 10^4-year, 10^5-year, etc.); spatial (local, regional, global); and investigative (descriptive, processual, predictive, etc.).

Finally, our discussion of variability addressed the difficulty of defining boundaries to normal ranges, problems of prediction inherent in quasi-periodic phenomena (e.g., those statistically centered at around ten years but ranging from five to twenty-five years), and phenomena such as ENSO, with a predictable appearance every three-and-a-half to four years but with extremes that are unpredictable but considered within normal variation (such as the strong ENSOs of 1982–1983 and 1997–1998 and yet more catastrophic "mega-Niños" that some archaeologists perceive in the Amazonian record [Meggers 1991]).

We intend this volume to integrate the complication of perceived variation into biophysical dimensions of variability. Human response is conditioned by the ways individuals as members of a community comprehend variability. The so-called normal variation of climate that falls within a tolerable range, for example, will of course differ from society to society. When variability exceeds that normal range, the response will be different, but the rate of response, the ability to find innovative ways to adapt, and the ability to tap the society's past experiences with similar extremes will also widely differ. A central theme of this book is such social memory. Some extreme situations can go beyond even the social memory arsenal of responses. These are the mode shifts that bounce regional climate into newly permanent, qualitatively different states (a new "normal envelope"; see below), with corresponding demands on human groups.

Archaeologists have discussed the ideas of perceived environment and perceived variability for some time (Butzer 1982). Perception is a nonlinear phenomenon. As countless psychological experiments have shown, human perception is not well suited to recognizing unanticipated deviation and change. Perception of variability is critical to the functioning of social memory, society's tool to curate useful information about past climate crises and effective adaptations to those crises. Societies differ widely in their ability to update climate knowledge, in the level of accuracy within that stored knowledge, and in the nature of the stresses that will alter the permeability of the knowledge filter. Deviations must have enough magnitude to trigger the perception that conditions are beyond the normal envelope. Perception focuses (nonlinearly) on events above a particular threshold rather than on anomalous but small episodes, or on a series of small changes, or even on incremental changes below the normal envelope's thresholds. Many of this book's chapters address the question of who in society records climate data and who may access those data to mobilize a response (e.g., McIntosh, Togola, Freidel and Shaw, and Hsu). The segments of society where these functions are lodged vary in hierarchical communities (such as early states or even the modern nation-state), with their relatively few gatekeepers, and more horizontally organized but still complex societies with many information specialists (heterarchies).

There is in all this a clear message for biophysical scientists wishing to use anthropogenically generated or anthropogenically modified proxy evidence for climate change: those in the historical sciences have experience with the contingent nature of perceived variation. Because the social memory of each group is contingent on a particular constellation of beliefs, values, and sociopolitical structure, not all human responses in the past have been based on an objective assessment of climate variability. The highly politicized responses of the delegates to Kyoto and of the political leaders to whom they report reflect the operation of this process today.

Mode shifts. Appreciation of abrupt changes to new, discrete climate states is one clear benefit of the past decade's advances in knowledge about

climate forcing mechanisms and local and regional sequences. *Mode shift* is defined as a rapid change of the central climate tendency. The changes involved in mode shifts go beyond the normal range of variation to establish permanence in a new set of boundary conditions, a new normal envelope. By analogy to the abrupt leaps described for the dynamic metastable equilibria of quantum theory or of self-organizing/self-regulating systems in natural or human ecology, one long-term climate trend, or mode, is separated from the preceding by a threshold (e.g., Butzer 1982:fig. 2.3).

Mode shifts complicate matters by being scalar, which is their particular significance for this volume. By definition, mode shifts are qualitatively different from persistent anomalies (e.g., new interannual precipitation amplitudes or harmonics) or from cyclical extremes within the normal variability envelope to which a particular society may have adjusted. For example, Trenberth (1990; see also Dunbar in this volume) speaks of a phase shift in around 1976–1977 to a period of more active ENSO events. This would not represent a full-blown mode shift in the terminology of this volume, because the more active (and occasionally quite high amplitude) El Niños are still within the upper boundaries of prior experience. True mode shifts are different even from the isolated, anomalous events that may exceed the boundaries but disappear in short order.

Mode shifts clearly affect human societies. Some suggest (simplistically) that they initiate political collapses, but as often they may stimulate increased complexity or provide opportunities to explore altered environments (see Tainter and van der Leeuw in this volume). One challenge for the historical sciences is to document how social memory is activated under stresses of different degrees. A similar challenge for the paleoclimatological community is to explain the scalar aspects, the frequencies, and perhaps the periodicity (or lack thereof) of these equilibrium-state disjunctions. Everyone must be enlisted together to work on the big question of the greenhouse gas and global warming debates: What can kick the global climate system up to and over these thresholds? Can the push be anthropogenic, caused, for example, by the atmospheric by-products of our industrial success? Clearly we must have a far better understanding than we do now of scalar mode shifts if we are to find answers to these issues: (1) How frequently in the past have we experienced mode shifts? (2) How long are these transitions? Do societies have mere months, or a year, or ten or twenty years, to adapt? (3) Have humans contributed to the onset of any mode shifts or amplified otherwise moderate shifts? (4) How variable are the naturally occurring states (intermode shifts)?

Many of the contributions to this volume document thresholds and new modes. Mode shifts of smaller scale (temporal and amplitude) are of course the most difficult to untangle in historical records from clustered anomalies that still lie within a mode's normal variation. In this volume, Dunbar deals with this issue primarily from a paleoclimatologist's perspective, when he asks not just whether the persistent climate anomalies recognized instru-

mentally since 1976–1977 (with attendant shifts in the ENSO and Pacific North American Pattern, including near-catastrophic precipitation changes in the central and southern United States) constitute full-blown mode shifts but also what status to assign regionally strong but nonglobal centennial-scale episodes, such as the Medieval Warm Period or the Little Ice Age. Similarly, the question for Dean (in this volume) is whether the high temporal variability episodes of the southwestern dendroclimatic record of around A.D. 750–1000 and 1350–1550 constitute true mode shifts, in light of their apparent reflection in changing Puebloan demography and settlement distribution. Togola (in this volume) argues that traditional West African communities had effective responses to the beginning of the Sahel drought in 1968 because elderly villagers recalled similar conditions in the early decades of this century. The alternative to systemic transformation is a tendency to jump around year by year, employing different short-term tactics while denying changing conditions. Denial of change is typical of all people who benefit from current conditions, including elites in both emerging early states and today.

We are on firm ground discussing regional or continental cultural responses to mode shifts at the next scale, those of multicentury duration such as reported in this volume by Hassan and McIntosh. The paleoclimate of lowland tropical Africa, in particular, reflects nickpoints or thresholds at 12,000–11,000, 8500, 7500, 4500, and 4000–3700 B.P., as well as around the beginning of the present era. Hassan argues that these were also the time markers for the most salient developments in the continent's prehistory (1997; see also this volume). Whether these moments were recorded equally in all parts of Africa, much less in every adjoining landmass, is still open to debate. McIntosh (in this volume) and Vernet (1995), while generally agreeing with the timing of these climate break points, shift emphasis to the apparent high climatic oscillations that appear to precede or immediately follow mode shifts. Such periods of high climatic harmonics lead to high economic and social distress and, in many cases, to intense innovations and reinventions of past adaptations as effective social memory kicks in.

Lastly, some paleoclimatologists mention the possibility of truly large-scale mode shifts powered by earth's orbital or solar-energy forcing mechanisms. These are global in expression and utterly transform the earth's climatic system. The Pliocene-Pleistocene and Pleistocene-Holocene transitions are well known. Others are actively debated. For example, Landscheidt (1987:433–438, esp. 437 and fig. 25-13) implicates several of the 391-year sunspot events as pushing earth's climate to a dramatically new central tendency. He invokes, in particular, the Egyptian Minimum of 1369 B.C. and the Medieval Maximum of A.D. 1126. The appeal of Landscheidt's approach is its apparent chronological accuracy. The next phase jump will come in about the year 2030, and it will be of an intensity equal to the Egyptian Minimum. We shall soon know if his work has predictive value. Our archaeological sequences may someday be of sufficient precision to test independently his

assertion of global synchroneity to the catastrophic effects of each mode shift. Another example is Mörner's (1987) "planetary beat" (see below). While these mega–mode shift hypotheses may remain at the fringes of paleoclimatological research, they do not deserve to be politely ignored by the climate modeling and simulations communities, as they are at present. If these mode shift thresholds are as spectacular and abrupt as some believe, then they may well have been recorded in many communities' deep-time memories of past environmental change.

Modeling and simulations: Filtering, retaining, and transmitting experiences. A useful introduction to the concept of social memory will be a comparative discussion of an alternate, yet in many ways parallel, set of climate modeling techniques. Social memory shares many attributes with scientific simulation strategies that employ vast data sets in dynamic, synthetic constructs generically called general circulation models (GCM). These use powerful computers to model ancient as well as future climate trends. Scientific climate simulations generated by climate mechanism models that look at the changing links among atmospheric, oceanic, land-surface, and sea-ice components form a significant portion of the 1995 IPCC volumes (Kattenberg et al. 1996), as well as of that panel's congressional and fossil fuel industry criticisms (Gelbspan 1997:63–83, 197–237).

At the time of the first IPCC report in 1990, GCMs were somewhat primitive. There is now, however, consensus in the discipline about the powers and remaining weaknesses of the twenty-seven current modeling or simulation projects constructed to be predictors of future climate change. This consensus is due in part to the dialogue, mostly friendly but sometimes acerbic, among proponents of the various projects. That the dialogue is open is demonstrated by the great efforts made by the IPCC authors to submit all these coupled models to open, rigorous peer review (Gates et al. 1996).

The modeling efforts of climate researchers have analogs in the selection, curation, and exchange of data for social memories. The comprehensive evaluation of multiple GCMs published in the 1995 IPCC report (volume 1) is just the most recent iteration of the climatological community's historical attempt to compare the robustness of different models across different simulation dimensions, which now includes virtually all global atmospheric models in the international Atmospheric Model Intercomparison Project (AMIP) (Gates 1992). The ultimate purpose of all this effort, computer time, and considerable debate is to filter from the millions of climate variables and spatial and temporal relationships those variables whose sets of boundary conditions are most useful for prediction and also manageable with current computational technology. These simulations reflect the model builders' decisions about filtering, retaining, and transmitting observations about climate dynamics. Equally relevant for the purposes of this volume are scientific attempts to model global paleoclimate at specified baseline moments in the past. Here the playing field is much reduced (with COHMAP—see below—the current titleholder). We argue that the filtering, retention, and transmis-

sion functions of paleoclimate models and future climate simulations illustrate key functions of non scientific social memory.

All projects simulating, modeling, or otherwise designed to explain the past functioning of climatic systems share a fundamental structure. All filter out extraneous data and curate and commit to memory the data or causal factors deemed most important. For example, AMIP evaluations have progressively tweaked greater consensus among modelers of the importance of cloud radiative effects, ocean surface fluxes of heat momentum and fresh water, and the radiative effect of aerosols (including anthropogenic ones). All modeling projects also have a component of interface with the world of action (even if it is just to make predictions of low-level probability about future climate change).

Few paleoclimatologists would argue that progress in the field has been along a straight, unproblematic path to ever greater powers of simulation. Few paleoclimatologists need to be reminded of the historical suppression of the concept of Milankovitch forcing mechanisms (the development of ice ages by regular variations in the earth's orbit and spin axis) (COHMAP Members 1988:1043; Imbrie and Imbrie 1979:97–122; Wright 1993:1). Given this historical perspective, we are interested in the critical self-examination within the community of modeling scientists that helps us understand why some research protocols are selected and others ignored, why some data are privileged and others not, and, if we are very fortunate, even how certain core values of the community of scientists determine the essential questions that community asks about the causes of global change.

We look first at some paleoclimate modeling projects in the Western scientific tradition (particularly the COHMAP project). Then we will move to a slightly more abstract plane to introduce the concept of social memory as the bridge across the domains of implicit values, protocol, culturally selected data, and (finally) the world of social action. Many of this volume's archaeological and historical manifestations of social memory are ultimately unscientific, in the sense that they come out of cultural traditions that attribute an overwhelming vitalistic force to the world (McIntosh, Freidel and Shaw, and Togola) or are parts of magico-religious worldviews (Hassan and Hsu). Because they lack skeptical testing, a goal of falsifiability, and other sine qua non of Western science, the analogy of social memory with paleoclimate modeling should not to pushed too far. (Western science is, after all, explicitly self-correcting.) Nevertheless, both have prediction as a goal. Both have as their ultimate tasks to (1) allow the community to sort through past experiences of climate change; (2) find a mechanism to curate and preserve those experiences in a way that can be passed on to fellow members of the community and, especially, to future generations; and (3) authorize action in situations of changing climate. Let us turn to a behind-the-scenes analysis of one of the most influential paleoclimate modeling projects, COHMAP.

The Cooperative Holocene Mapping Project (COHMAP Members 1988; Kutzbach et al. 1993) illustrates nicely the choices that inevitably must be

made even in a multicollaborator, high-budget, computer-driven research project. This project was not the first global paleoclimate model. Earlier attempts, most notably the CLIMAP (Climate, Long-Range Investigation, Mapping, and Prediction) program (CLIMAP Project Members 1976) designed to estimate sea-surface temperatures (SST) at 18,000 years B.P., were hamstrung by omission of certain pacemakers of climate change or rhythm, such as orbital eccentricities (COHMAP Members 1988:1043; Hays, Imbrie, and Shackleton 1976). More recent models, such as the Paleoclimate Modeling Intercomparison Project (PMIP) (Gates et al. 1996:270–271), have revised the SST and ocean-mixing data in light of the AMIP evaluative experience. But COHMAP still holds the respect of most of the modeling community and so will repay closer examination.

The Cooperative Holocene Mapping Project is a congeries of causative components and supporting data. Its model of causation is driven by the assumption that most power can be derived from a simulation of the relationship between changes in solar radiation and surface boundary conditions. The project employs the general circulation model called the Community Climate Model of the National Center for Atmospheric Research to command boundary conditions such as ice and snow cover, land albedo, mountain and ice-sheet orography, and sea-surface temperatures. Variation in top-of-atmosphere insolation is determined from reconstructions of historical, orbitally induced variability (especially the 22,000-year precession cycle and the 40,000-year cycle-of-axis tilt). Other longer-period or short-duration orbital variations are not included. Ocean circulation reconstructions, those flux adjustments featured so prominently in the 1995 IPCC report (Gates et al. 1996:237), are not included. The well-known sunspot cycles of solar radiation are not included; neither are reconstructions of atmospheric aerosol reduction of incoming solar radiation, nor recent revelations of a lunar (synodic) cycle to global temperatures (Szpir 1996). Human environmental impacts with the emergence of agriculture or pastoralism are similarly excluded. Clearly there has been much filtering and selection among potential variables and data. There has also been filtering of the paleoclimatic data used comparatively to verify the model predictions. The principal data are pollen, lake levels, and marine plankton. There is very little discussion of why tree ring or ice core data, or packrat middens, or coral cores, and so forth were not selected.

The point is not so much to criticize these protocol choices as to point out that many other, perhaps equally robust variables could have been selected. One can appreciate the heroic efforts of the modeling team while at the same time wishing for a bit more discussion of how the filtering took place. Let us look at an example of a neglected alternative.

Within the Western scientific mode, a quite radical alternative championed by Mörner (1987) explains the short-term, often regionally expressed climate changes that have great relevance for archaeologists dealing with adaptation. Mörner has proposed a model of angular motion exchange by

which an initial acceleration or deceleration of the earth's mantle or crustal mass relative to the core would cumulatively change the solid, gaseous, and (especially) liquid layers and would also encourage clustering of volcanism, with the attendant cooling effect of the cumulative ejecta. The result is short-term redistribution of heat over the globe, regionally expressed as 0.5°C to 5.0°C events. Mörner's pulsing force of global climate rhythms (the so-called planetary beat) is quite independent of long-term Milankovitch effects and solar radiation variables, but with it he purports to explain many short-term (50–150–year duration) and mode shift events such as the 11,000 B.P. onset of the Younger Dryas, the 10,000 B.P. Pleistocene-Holocene boundary climate shifts, the 2500 B.P. northwestern European cooling, and the Little Ice Age. These short-term events or cycles and mode shifts are completely ignored by the COHMAP simulation. And yet the same Western scientific values generated both COHMAP and Mörner's planetary beat simulations. A further example is Landscheidt's supersecular sunspot events, discussed earlier, which are proposed to be caused by 391-year cycles of sunspot activity that are also ignored by the COHMAP group. His minima and maxima may allow us to postdict mode shift thresholds (or intense climate-induced surprises) of clear historical importance. In short, the COHMAP group has made certain decisions that, in effect, filter out dynamics of intense interest to the historical sciences.

Finally, unstated in all the descriptions of COHMAP's variables and simulation runs are the core values behind all these data and protocol selections. Clearly no such discussion was deemed necessary when all COHMAP collaborators—and all but the fringe of the entire paleoclimatological community—shared those values. The paleoclimatological community's values are (among others) falsifiability and replicability, deriving from Western rational skepticism. There is the assumption of the progressivist transience of modeling; that is, just as COHMAP evolved out of and corrected the weaknesses of the prior CLIMAP (Kutzbach et al. 1993:24), there is the implicit assumption that COHMAP too will one day be improved on. Further, COHMAP fits nicely the ideal of reductionist empiricism: in order to understand a phenomenon, base inquiry on its components and causation reduced to their simplest state. Reductionism, to be sure, has served Western science well for centuries. Yet here the role of the implicit (unarticulated) core values becomes clear. Reductionist empiricism stands in stark contrast to attempts to model multidimensional complexity at, for example, the Santa Fe Institute (e.g., *The Economist* 1994; Kauffman 1995; Waldrop 1992). In emerging-complexity theory, complex physical and social phenomena are analyzed and explained not in the atomized terms of component parts; rather, the whole is something not just larger than, but quite different from, the sum of those parts. This complexity paradigm has great and growing appeal to the student of historical social phenomena (McIntosh and McIntosh 1988:158–159; Gumerman and Gell-Mann 1994; Tainter and Tainter 1996b). It is also a core value behind the study of social memory.

Social Memory

Retaining and Transmitting Experiences

All archaeologists have ever done, or can ever do, is interpret what remains after people have acted on the world as they perceived it. It is therefore imperative that historical scientists pay attention to the social construction of reality. To tap into the intentionality of past peoples, we must work with a definition of the social construction of reality as the processes by which the metaphors that crystallize social action are manufactured. These metaphors, and their physical and behavioral manifestations, are the stuff of social memory (Schama 1995).

We are collectively all paleoclimatologists. All communities have had to develop ways to recognize climate crises early or, even better, to anticipate them and mobilize resources beforehand. We present social memory as a concept to describe the ways by which communities curate and transmit both past environmental states and possible responses to them. Far from being a stagnant pool of knowledge, social memory often involves innovation in the form of experimental recycling or reinvention of curated knowledge of past climate experience and of economic and sociopolitical strategies that previously provided solutions. Social memory in our context is the long-term (greater than three-generation) communal understanding of landscape and biocultural dynamics that provides for the curation of pertinent experience and its intergenerational transmission. It is largely ideological or mythological and may even reside in the sacred domain. Social memory may allow the community to designate those of its members who have authority to act in times of stress.[3] Social memory is thus the source of the metaphors, symbols, legends, and attitudes that crystallize social action. In the case of the Mande of West Africa, for example, Togola argues in this volume that the first function of social memory is to generate the symbols and protocols of reaction to weather extremes.

As several chapters in this book and other studies show, the social memories of various peoples reflect changing conditions of weather or climate (see Hsu, Freidel and Shaw, and Johnson in this volume; see also Bowden 1977:3–31); thus it will not do to dismiss social memory as made up solely of disjointed, irrelevant historical artifacts or picaresque, low-prediction archaisms. Hsu's discussion of Chinese perceptions of climate provides one of the best-documented illustrations of the formation and use of social memory. In south China, legends tell how Kun controlled floods with banks and dikes. This solution to a perpetual problem requires mobilization of large labor forces, for which the legend of Kun gives sacral legitimation. Proverbs predict how one state of weather leads to another, while poems and songs encode pragmatic observations on the environment. Whether such bits of folklore always predict phenomena accurately, their primary value is to deploy authoritative, local traditions to initiate problem solving.

The contributors to this volume find social memory to be a powerful unifying concept for looking at the vast range of human responses to climate

change, at very different time scales and in such diverse places as China, Egypt, Mali, and the Yucatán. The concept, we suggest, can help historians and archaeologists leap the disciplinary hurdles between the historical and biophysical sciences. As used by members of the global change workshop, social memory links the symbolic reservoir, that is, the authoritative set of symbols, metaphors, and myths that derive from core values (deep-time and unarticulated) fundamental to a society's perception of the meaning of space and of its own place in nature, and social action, that is, community and individual action conforming to appropriate authority. This linkage is through schemata, as discussed below.

Social memory transcends intergenerational instruction of first-hand, if imperfectly remembered, climate facts (such as, "When I was your age we walked seven miles to school, waist deep in snow drifts"). It even transcends the apparently idiosyncratic bits of climate stories passed on, for example, in the Bible (Issar 1995). Social memory can be likened to a calculus that allows society to reinvent responses to the environment in the face of environmental change. As a calculus it allows for many of the key transformations of history, for the recasting of core ideas from a deeper past so they can be used to respond to the new circumstances of the moment (as early Christians recast gods and goddesses into saints). A community's selective memory of climate and the process by which social perception of landscape filters out or highlights climate data play important roles in the construction of reality.

To address social memory, archaeologists and historians have to confront their own disciplinary history of overly simplistic, overly mechanistic, or just-plain-faulty paradigms of human response to climate change. Behind the rehabilitation of climate and ecology in prehistoric archaeology is, perhaps, an acknowledgment that these topics can provide a window on motivations and intentionality in the distant past (e.g., van der Leeuw 1998).[4] What makes this new perspective on environmental adaptation so different is that it no longer assigns society a passive role, as was the case in the 1960s and early 1970s. There is now an appreciation of the complex (and recursive) relationship of climatic inputs to culturally created perceptions of climate (*schemata*, in the terminology of this volume). Communities do not simply react to climate change and environmental surprise. Rather, they actively sort through information about past climate and about successful (or disastrous) responses. This mandates that we understand how climate history is transmitted from generation to generation, along with other, related matters. How are culture-specific models of environment generated and maintained? How does social perception of climate change come to be translated into social validation of adaptive action? A historian or prehistorian interested in human responses to climate change will take as an appropriate topic of study the deeper values that intimately affect the selection of bits and fragments of a community's past experience with climate change. The complementary concern is how that community then employs those memories in its search for appropriate responses to changing climate conditions in the present. To

comprehend these issues we have to understand the cultural context that allows past experiences to be filtered and selectively curated.

Symbolic Reservoir

The symbolic reservoir guides a community's formation of perception (Berns 1993; David 1992; MacEachern 1994; McIntosh 1989, n.d.; McNaughton 1993; Sterner 1992). The symbolic reservoir is the domain of the implicit behind both social memory and schemata (fig. 1.2). For it to make sense and be passed on to the next generation, social memory must be coded in the foundation legends, beliefs, and material cues that serve in turn to structure a society's perception of its environment. That perception can provide both a general model of climate change and specific prescriptions for situations of stress and for risk.[5] These symbols or perceptions of the physical or social environment are based on deeper cosmological principles that give a historical trajectory to the social construction of reality. The symbolic reservoir furnishes those principles.

We use the term *symbolic reservoir* to indicate the fluid repertoire of ideological, symbolic, metaphorical, and mythical notions that gives all societies their dynamic consistency over time. By analogy with components of scientific paleoclimate models, such as COHMAP or PMIP, the symbolic reservoir is the set of unconscious operating assumptions and generalized analytical procedures (but not the specific protocols) employed by communities

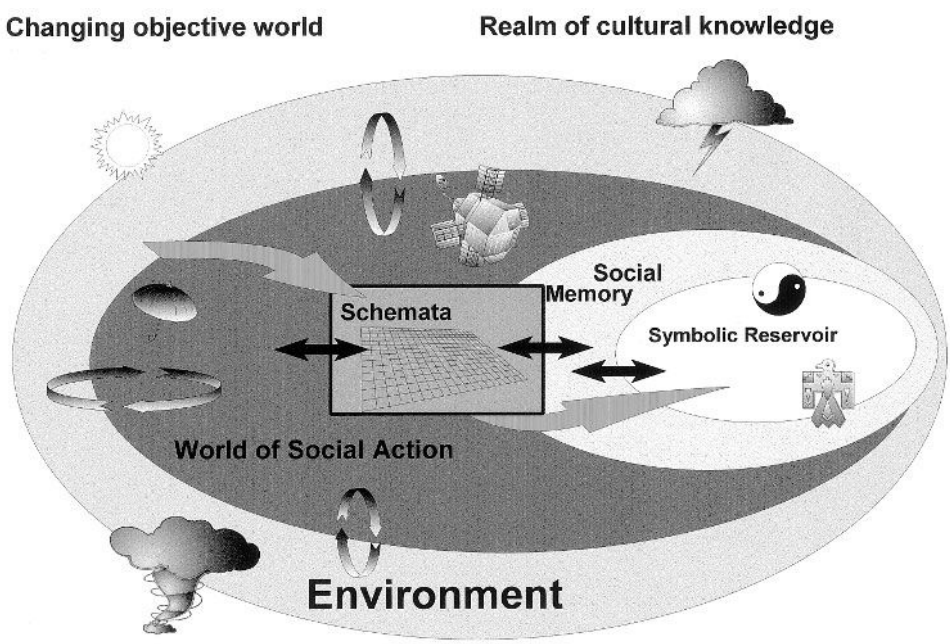

Figure 1.2.
Social memory, symbolic reservoir, and schemata.
Illustration by Richard Periman.

to develop shared perceptions.[6] It is the wellspring of values, symbols, and ideologies from which different subgroups of a society take the framework to form social memories. In Chinese cosmology, for example, the symbolic reservoir consists of those cosmological postulates within which all phenomena are categorized. These include such concepts as the role of equilibrium in the cosmic order, cyclicity and the impermanence of any extreme, and the role of morality in maintaining balance. Together, as Hsu shows in this volume, these postulates structure how Chinese for centuries have perceived weather and climate.

Cultural Schemata: Criteria for Filtering Experiences

Any adaptive system, in Gell-Mann's description, functions to acquire "information about its environment and its own interaction with that environment, condensing those regularities into a kind of 'schema' or model, and acting in the real world on the basis of that schema" (1994:17). Much of social memory is by definition subliminal. A cultural schema is the socially agreed-on framework for debate about how the world works, the framework of understanding and communication that allows community decision making and mobilization. It is the framework of shared knowledge about relationships in the environment and human responses. A cultural schema derives from the cosmological postulates of the symbolic reservoir. Schemata are cultural maps for action: a schema determines a system's response to new information. Schemata relating to climate change work integrally with a living community's memory or, as Hassan argued in the global change workshop, at the scale of sixty to one hundred years.

Hsu's discussion of Chinese cosmology in this volume again provides well-documented examples. In the Chinese case, the schema consists of such things as yin-yang dualism, the theory of five agencies, *fen-sui* as a filter for past experiences, and the interpretation of the cosmic order based on mechanic naturalism. These concepts filter and categorize weather phenomena. They derive from the symbolic reservoir (equilibrium, balance, cyclicity, morality) and serve in turn to structure both the forms of social memory (legends, poems, songs) and social action (humanity—especially rulers—responsible for maintaining harmony) (see fig. 1.2).

Schemata provide the filters for perception. Societies categorize deviations and changes on the basis of schemata. Deviations or new patterns to climate must have enough magnitude for perception to be awakened. Schemata will probably filter out random episodes or even a series of small episodes. Incremental change below the threshold defined by schemata will also likely be ignored. But if change registers as exceeding the specification of the cultural blueprint for the normal range of the combined physical, social, and symbolic landscapes, then society acts.

With such concepts we seek to understand how climatic surprises, paleoclimatic cycles of different periodicities, and major modes of climate are imprinted in social memory, "captured" in Gunn's felicitous term (Gunn

1994:68, 82–90). We seek to understand, for example, specific adaptive strategies (Tainter and Tainter 1996b), such as Hohokam irrigation versus Chacoan regional exchange (Crown and Judge 1991) as decisions that make sense within varying schemata of the environment. Some schemata may ultimately prove to be poorly suited to climate change, as in McGovern's (1994) example of Norse Greenland. Others may prove to be highly flexible and stable, such as solutions to the potential conflicts of different ethnic groups occupying the Middle Niger Valley, a highly changeable semiarid tropical floodplain (McIntosh 1993:206–212, and this volume).

Schemata may be shared cultural maps, but they can be shared differentially within the community. Even in the smallest-scale, simplest society not every member will perfectly replicate the environmental knowledge and structuring mental framework of everyone else. Differences of age and sex guarantee variation in experiences. The greater the diversity in the community's schema, the greater the environmental diversity that can be processed. The potential adaptive strength of complex societies lies in the fact that such societies create more variations on cultural schemata to filter data and to guide the entry of knowledge into social memory. To generate diversity, complex societies need to encourage (or at least tolerate) subgroups' knowledge collection so that pooled information will encompass a greater range of climate variation and store a larger set of past behaviors. Fundamental to this process of complexification is the manufacture of authority: who can tap the stored knowledge, who can frame decisions in terms that make sense according to a reigning schema, so that society can act.

Authority and Legitimacy

Social memory is effective in that it is authoritative, and it is authoritative in that it is legitimate. In this it partakes of the socialization process itself, the very thing that makes human culture possible. The secret of socialization is that it is self-obscuring. A human child is taught from birth that a cultural order is a natural order. Since those doing the teaching were themselves socialized in the same way, socialization is substantially self-enclosed and self-perpetuating. Unless there is prolonged contact with others, the process requires little or no self-awareness (thus many indigenous self-names mean something like "the people" or "the human beings"). Only where there is prolonged cultural contact does explicit cultural identity need to be an assertive part of social legitimation.

Social memory gains its authority from this legitimacy. Residing as it does in cosmologies, myths, oracles, performances, and artifacts, social memory is part of the natural order. It conveys meanings that could not properly be otherwise, that reflect the world as it ought to be. Thus sanctified, the values and messages of social memory command immediate attention. Not only is social memory not to be questioned, it does not occur to most people that they could question it or even that they might wish to.

Where social memory conveys experiences that are appropriate to con-

temporary environmental stress, its authoritative nature allows for rapid responses. Yet where social memory does not convey an appropriate message, its authoritative nature is something to be overcome (see, for example, Hassan's discussion in this volume of a contemporary Egyptian government adviser). This may be the case now, when environmental conditions are emerging that have either no historical precedents or only very remote ones. To the extent that this is the situation today, policies to respond to climate change will most easily be implemented to the degree that new circumstances and actions can be translated into the authoritative canons of rural social memory.

Distribution of Social Memory

Social memory is unevenly distributed and always has been. It is differentially distributed within each society, even those that are quite small. Within egalitarian societies, social memory varies with the sexual division of labor and along other lines. It is sometimes found where one would not expect it. Within villages in southern Mali, for example, there is a class of hunters, whose membership is less than the set of all adult males. They are held in great respect and membership is highly valued, even though today there is little large game for them to hunt. With their knowledge of the landscape, though, they are specialists in locating medicinal plants and know intimately the conditions under which such plants produce. The fact that hunters have this special knowledge is not secret but is not immediately apparent to an outsider (who might assume, naturally enough, that hunters hunt). Their esoteric knowledge is social but not society-wide.

Knowledge is power. The differential distribution of social memory gives a corresponding distribution of power in a society. To possess valuable social memory is to have prestige or authority. Social memory can thus be linked seamlessly to hierarchy, with each reinforcing the other.

The integration of social memory to hierarchy is particularly forceful where it has sacral elements. Religion is the ultimate legitimizer and provided the authority by which states originally formed. A critical impediment to the development of states was how to integrate autonomous, local units, each of which had its own interests, jealousies, and feuds. A ruler drawn from one group was automatically suspect by the others. The solution to this structural limitation was explicitly to link leadership in early complex societies to the supernatural. Thus early states (like those of today) had an explicitly sacral basis of legitimacy, employing an overarching scheme of cosmology, ideology, and symbols to unite disparate, formerly independent groups (Netting 1972; Claessen 1978; Skalnik 1978). As Hassan, McIntosh, Hsu, and Freidel and Shaw note in their chapters in this volume, sacral legitimacy is commonly linked conceptually to an obligation for leaders to provide good weather (just as leaders in industrial societies today are supposed to provide a good economy).

It is wise never to underestimate the power of social memory in political legitimation. A former president of the Navajo Nation, for example, was considered by many to be corrupt and eventually was sentenced to prison.

Despite his well-publicized problems, he managed repeatedly to be elected to office. The key to his success is said to have been his ability to go into rural areas and recite traditional Navajo myths and stories, relating these to contemporary circumstances. This was social memory in action, drawing on authoritative experiences of the past, coded in myth, to serve as a template for contemporary responses.

While political hierarchy probably requires the sacral legitimation of social memory, the reverse is not true. Social memory functions quite normally in the conditions that Carole Crumley has termed *heterarchy*. Heterarchy is horizontal social differentiation. Crumley defines it as social systems "in which each element possesses the potential of being unranked (relative to other elements) or ranked in a number of different ways" (1979:144). Heterarchy pertains to such elements of horizontal differentiation as occupational specialities, moieties, sodalities, ethnic groups, city-states, and peer polities.[7] The differentiated ethnic mosaic of the Middle Niger Valley, described by McIntosh and McIntosh (1980), is a consummate example of heterarchy, as were the developing polities of the Aegean in the Archaic period (Renfrew 1982, 1986).

Hierarchy and heterarchy influence the channels in which social memory operates and by which it is conveyed. They differ in the speed and scale at which they operate and the rates at which they change. The levels in any hierarchical system behave at different rates; these differences are one of the defining elements of hierarchy (Allen and Starr 1982; Allen and Hoekstra 1992; Ahl and Allen 1996). Higher levels constrain lower levels, but, contrary to intuition, the constraint is not always active. Higher-level elements constrain those further down largely by acting at a lower frequency. Elites limit the behavior of subordinates by being unresponsive. Constraint is achieved by doing nothing, hence the famous inertia of bureaucracies. While lower levels in a social hierarchy go about the high-frequency business of daily life, the higher levels grant an occasional appeal or bring forth an edict. In a classic study, Fergus Millar (1977) showed that the Roman Empire functioned largely on the basis of standing orders, supplemented by the right of a citizen to appeal all the way to the emperor. Such appeals, naturally, might take years, and a personal appeal could take months of arduous, expensive, dangerous travel. The citizens of the empire were thus constrained by the slowness with which they could access the hierarchy and petition it to act.

In most living systems, information flows upward to higher levels, and constraints operate downward. The higher levels respond not to the primary forces felt by lower levels but to information about those forces. Information flowing upward is always filtered, and higher levels are routinely unresponsive to information from below. Elites in human societies typically respond most carefully to horizontal social signals: messages from or about other elites. A Russian colleague, for example, described to one of us (Tainter) how Mikhail Gorbachev behaved in the waning days of the Soviet Union. As the union crumbled around him and its citizens and security forces battled in the streets, the information that mattered personally to

Mikhail Gorbachev was not the demands of lower levels but his reputation among Western leaders. This external, horizontal, heterarchical information influenced his internal, hierarchical policies. Similarly, in August 1996 there was much discussion of establishing a high-speed rail line between St. Petersburg and Moscow. At the same time the local rails within St. Petersburg were so dilapidated that in places they ran over mud. The upper levels of civil administration in St. Petersburg responded to horizontal signals from civic elites in Moscow, while reacting callously to local distress.

It is the same with social memory. The advantage of hierarchy is that it can act quickly, uniformly, and over a large area. Hierarchy conveys the authority to mobilize communities to act, and to act quickly. It can aggregate resources for a more effective response to stress and can ensure that benefits are distributed equitably. What hierarchy typically will not do is respond quickly to signals from below. When subsistence producers signal distress to upper levels, the message may often be ignored, or misunderstood, or addressed incorrectly. As the Abbasid caliphate declined economically in the ninth century A.D., for example, the caliphs demanded taxes of peasants regardless of their ability to pay. At times taxes were demanded before a harvest, even before the next year's harvest. As a result, the peasantry, the agricultural production system, and the caliphate were all destroyed, and the population of Mesopotamia plummeted (Adams 1978, 1981; Waines 1977; Hodges and Whitehouse 1983; Yoffee 1988). Hierarchies respond poorly, slowly, or not at all when signals from below indicate a need for structural adjustment. In a sense the 1995 IPCC report on the economic and social dimensions of climate change (Bruce, Lee, and Haites 1996) reflects this phenomenon, for within its learned chapters one finds little discussion of responses to environmental change in indigenous production systems.

Heterarchy, while not so effective at mobilizing intercommunity responses, has the advantage of being better suited to acknowledge and incorporate varieties of experience. Heterarchical systems operate either by consensus or by ad hoc consensual leadership. While the process of adjusting to new circumstances is unavoidably slow, it derives its legitimacy from consensus. Those who have participated in developing a heterarchical consensus are intrinsically committed to implementing it and will experience strong social pressures should they fail to do so. Yet while the lower levels in a hierarchy generally act at a higher frequency than higher levels, heterarchical social memory may change at speeds too slow to accommodate rapidly changing circumstances. Thus, while heterarchy has the advantage of incorporating diverse experiences and ensuring legitimacy of decision making, it falters when conditions call for rapid, uniform responses or mobilization of regional resources.

Social Memory: Implications for Policy

Social memory, and its role in guiding human responses, has substantially been overlooked in discussions of how to respond to global change. This failure is

not surprising, for high-level scientists and officials act like the upper levels in all hierarchical systems. They act only on filtered, aggregated information and respond slowly if at all to signals from lower levels. Carole Crumley's chapter shows clearly how the high-level economists and diplomats who design international trade agreements act blindly with regard to local social memory. In so doing they destroy local production systems of sustainable agriculture that have persisted for generations or centuries.

One of the implications of this book is that economists and policy makers should familiarize themselves with the phenomenon of social memory and consider its role when formulating responses to global change. This knowledge cannot usually be developed at the national level and certainly not at the international. Social memory must be documented and understood at the local level. To comprehend it and its role in climate change requires anthropological fieldwork among a great many communities and production systems around the world. This will seem a daunting task, but failing to pursue it will mean that economists and governments will continue to formulate policies that may hinder local adjustments to environmental change.

In studying such local contexts it is important to understand the degree to which social memory is transmitted hierarchically and heterarchically. In most communities there is surely some of both, but the information conveyed by each channel may be quite different. There is moreover a degree of interplay between them. Heterarchical social memory, as noted, changes slowly, but it can be led to change with gentle, persistent encouragement from above. Yet ironically its very resistance to change makes heterarchical social memory especially important in climate change. By human standards, even today's comparatively rapid climate transformation is a slow change that will transcend generations. Local communities may have time to adjust, and this is to be desired, for it will ensure that the responses are based on local circumstances and are considered legitimate.

One implication of the importance of heterarchical social memory concerns cultural conservation. Just as many agronomists now realize that indigenous strains of cultigens should be conserved, so also indigenous social memory should be. It is a great repository of human experience that would be tragic to lose. A successful response to global change will need to be legitimate, appropriate, economical, and locally sustainable. To achieve such a response we must tap the great reservoir of human experience.

Organization of the Volume

We have divided the book into four parts. The first, titled "Climate, Environment, and Human Action," groups together two papers that synthesize the fast-breaking developments in paleoclimatic modeling. In recent years, as we have discussed, a virtual revolution in the physical sciences that com-

prise paleoclimatology has produced much more refined knowledge of the physical forces that shape climate and greater resolution in paleoclimatic reconstructions. Robert Dunbar sets the stage for the social science papers in his synthesis of climate variability during the Holocene. He notes that while the modern instrumental record is a good place from which to start to examine this variability, it does not encompass it. Understanding today's climate requires that we comprehend paleoclimates. Research indicates that several mechanisms force climatic patterns at various geographical and temporal scales. El Niño/Southern Oscillation forces global variations in temperature and precipitation at periodicities of two to ten years and again at twenty to one hundred years. Other global or hemispheric climate systems include the monsoons, the Pacific/North American Pattern, and the North Atlantic Oscillation. Quasi-periodic variations on such timescales, argues Dunbar, allow for cultural adjustment, while abrupt, less predictable events such as century-scale droughts may be difficult to accommodate.

Jeffrey Dean's chapter bridges paleoclimate and human adaptation, employing the rich data of southwestern prehistory. He applies concepts of social memory and complexity theory, which he combines with evidence of high- and low-frequency environmental variability in the Southwest (concepts similar to the periodic vs. quasi-periodic distinction noted by Dunbar). Prior to A.D. 800, populations levels were low enough that environmental stress could be met simply by moving to an unoccupied area. After A.D. 900, however, population grew under favorable conditions and expanded into nearly every part of the Southwest. Cultural complexity increased with population and with the establishment of large, sedentary communities. Thereafter environmental variation influenced the human population more closely. Political systems disintegrated and large areas were abandoned during prolonged stressful periods from A.D. 1130 to 1180 and 1270 to 1450. During more benign periods there was greater cultural stability, although after around A.D. 1300 much of the upland Southwest was permanently abandoned by sedentary agricultural peoples.

The second group of papers comes under the heading of "Social Memory" and exemplifies that concept. Fekri Hassan traces the history of the intellectual developments that led to our current conception of social memory. He notes that perceptions of environmental variation can be skewed by cultural schemata, pointing to the example of an Egyptian ministerial adviser who detected in twentieth-century Nile flood data a pattern of seven high years, seven low years, and six years in between. The inspiration for his model, it turns out, is a reference in the Koran to seven years of abundance and seven years of drought. The concept of seven-year droughts is remarkably persistent in Egyptian social memory, dating back to the Old Kingdom (ca. 3100–2181 B.C.). This modern Egyptian analyst formulated his advice based on a continuum of social memory extending over at least four thousand years. Such an example underscores the power of social memory and its potential for persistence.

Roderick McIntosh and Téréba Togola, in their respective chapters, bring the perspective of the geomorphologist-archaeologist to understanding the very old roots (perhaps originating in the Late Stone Age) of the West African Mande occult concept of the weather machine. In this conception, the human ability to predict and direct weather is integral to a view of the world as a manipulable power or energy grid. Heroes, as they undertake quests, master such power. Power is related to places, and thus the cosmology is inscribed on the landscape. Animals guard and sustain these places, while hunters maintain correct social relations to minimize disruption of the climate. Togola illustrates these matters in a discussion of the legend of Wagadu. Environmental crises result from the malevolent actions of people or spirits.

Carole Crumley looks closely at Burgundian gardens, which, like gardens everywhere, help to reduce risks associated with inclement weather. Burgundian gardens today carry a tradition dating back to at least the first millennium B.C. Gardens reflect the order ascribed to the broader world and offer both personal and social mnemonics. They conserve traditional species and knowledge and are the source of new experiments. Today, national policies and international agreements are forcing Burgundian farmers to forgo traditional practices and intensify production. Sustainable production practices are being undermined. The broad lesson is that social memory is effective at the local level and can rarely, if ever, be transmitted or assimilated vertically.

The cosmology of China includes humanity's oldest continuum of social memory. Cho-yun Hsu traces those aspects of this tradition that concern climate. Local lore and proverbs guide farmers to the appropriate responses to short-term conditions. As in other traditions, weather in Chinese social memory is subject to human actions. Ministers and even emperors can be criticized for unfavorable environmental conditions. Loss of the Mandate of Heaven (a dynasty's moral authority to rule) is often heralded by unusual clusters of misfortunes, including weather unfavorable to agriculture.

Three chapters, grouped under the heading "Cultural Responses to Climate Change," cover opposite ends of the spectrum of cultural complexity: the Maya and the Chumash. Joel Gunn and William Folan model the responses to global factors of three rivers in the Maya lowlands. The Candelaria River responds strongly to Northern Hemisphere tropospheric temperatures, the Usumacinta River varies in regard to subregional forces, while the Champotón responds more to human modifications of its basin. Gunn and Folan discuss the relationship of these varying hydrologies to regional patterns of settlement and developing complexity.

David Freidel and Justine Shaw approach the Maya from a different perspective. Maya documented ethnographically and historically have emphasized rituals of crop maintenance and harvest where agriculture is risky. There is every reason to expect that prehistoric Maya had the same concerns. Freidel's work is at the forefront of breakthrough research of international significance: the translation of the Mayan script. This effort is only begin-

ning, particularly in regard to how ancient Maya viewed their immediate environment. The information is probably encoded in metaphors that today are utterly obscure. Freidel and Shaw suggest that with the tumultuous events of the ninth century A.D. (including the collapses of many southern Maya lowland polities and severe depopulation), Maya historical consciousness changed from a linear to a cyclical conceptualization, and thereafter Mayan histories are more explicit about the environment. If Classic Mayan rulers—like Egyptian pharaohs and Chinese emperors—were considered responsible for the well-being of the populace, then environmental references may have been coded as political messages in Mayan writing.

The Chumash of the southern California coast were among the most populous and complex hunter-gatherers that have been documented. Prolonged droughts and warm sea temperatures between A.D. 900 and 1300 led to both increased warfare and the development of an exchange system based on shell-bead money. This heterarchical economic system afforded some chiefs the opportunity to enhance their standing, leading to increases in hierarchical organization. Thus adjustments to climate included the development of a more differentiated system of social ranking.

In our concluding section, titled "History and Contemporary Affairs," two chapters explore the potential for archaeological and historical research to clarify today's environmental challenges and our responses to them. Many scholars have tried to ascribe cataclysmic consequences to past climate changes, asserting that they have even caused large and complex societies to collapse. Joseph Tainter examines these claims, finding that logically they cannot explain historical collapses. Of greater importance than climate per se is the fact that over time societies often experience transformations in their ability to deal with such problems as environmental change. Often this comes from historical changes in a society's return on investment in complex institutions. Collapse becomes more likely when a major challenge, such as an abrupt climate change, coincides with a prolonged period of diminishing returns to problem solving, making problem solving ineffective. Thus the social and economic context determines whether environmental change is truly a challenge. Tainter proposes that by providing a better understanding of the history and development of problem-solving systems, the historical sciences can contribute importantly to comprehending our capacity to adapt today.

In the final chapter, Sander van der Leeuw discusses the implications of the ARCHAEOMEDES multidisciplinary research program in the Mediterranean Basin. This research involves timescales ranging from decades to tens of millennia and thus is concerned with the interaction of processes that have quite different rhythms. Few research projects have taken so broad a view (see van der Leeuw 1998). Van der Leeuw points out that land degradation is a social construct, without absolute reference. It is both normal and temporary. Many popular conceptions of degradation do not stand up under close scrutiny. It may, for example, manifest itself in an increase of vegetation rather than in denudation. Most significantly, as a landscape degrades, new

economic opportunities arise even as old ones are closed off (see also Allen, Tainter, and Hoekstra 1999). Neither the concept of degradation nor its human consequences can be viewed as absolute. Both are relative to human perception and flexibility. Once this point is understood, discussions of the consequences of environmental change can never again assume that there is a simple, linear relationship between environmental characteristics and human well-being.

Notes

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2. There has been a parallel tendency among some sociocultural anthropologists and even historians toward studied ignorance, if not dismissal, of climate and environmental impingement on human affairs and even of the deep ecological time that is a subject of this book.

3. Our present understanding of social memory generates many questions. Can social memory, for example, register a record of long-term cyclical events or of unique episodes, such as multiyear cooling stemming from large atmospheric loading of volcanic aerosols? Will memory decay if similar or analogous events are not repeated within a certain period or if they are highly deviant? No society cycles through its own history (although Maya civilization was predicated on that very belief), so how can a society's perception of its own history square with a history of impinging climate that, in many cases, demonstrably does cycle? Such questions underscore the exploratory nature of our knowledge of social memory of environmental matters and how little research the topic has received.

4. Other advances have of course contributed to this rehabilitation. Baseline paleoclimatic data (regional and global) have improved enormously. Better knowledge of past climates in many regions has allowed a much more nuanced appreciation of "society's capacity for revitalizing its organization and developing coping strategies" (Hassan 1994:159). Moreover, those studying sustainability policy have recognized the need for a deep-time perspective on adaptation (Crumley 1994a:8; Gunn 1994:96–97; Issar 1995:350; McIntosh 1992; Tainter 1995; van der Leeuw 1998; see also Crumley, Tainter, and van der Leeuw in this volume).

5. Stress is defined as the consequences that arise when peoples' energy needs (nutrients, extrasomatic caloric requirements) are not met. Risk is the likelihood that this will happen, expressed as probability distributions of stresses of various durations and degrees of intensity (Tainter 1996b:15).

6. Similar to Kuhn's (1962) concept of "paradigm."

7. For the concept of peer polities, see Renfrew (1982, 1986).

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Part 1

Climate, Environment, and Human Action

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Chapter 2

Climate Variability During the Holocene: An Update

Robert B. Dunbar

Our view of Holocene climate variability is rapidly changing, based in part on increased knowledge of large-scale climate systems such as the Southern Oscillation, Asian monsoon, North Atlantic Oscillation, and Pacific–North American Pattern that interact and impart climate variability to far-flung areas of the globe. There is also a greater appreciation for the diversity of climate variability. Early suggestions of globally synchronous cooling and warming, such as the Little Ice Age and Medieval Warm Period have given way to a better-documented view that late Holocene climate variability is expressed as multidecadal temperature anomalies of about 0.5 to 1.5°C that tend to be region-specific (Bradley and Jones 1992; Hughes and Diaz 1994; Jones, Bradley, and Jouzel 1996; Overpeck 1995). In the tropics and parts of the midlatitudes, hydrologic variability during the Holocene appears to have been larger than expected from modern instrumental data and may in fact be more important than temperature as an indicator of climate change.

Current efforts to understand the Holocene are driven by a renewed interest in resolving so-called natural variability in the climate system on seasonal-to-centennial timescales as a prerequisite for the identification of anthropogenic impacts. The continued development of numerical climate models has also played a role. Models not only suggest regions and systems that are sensitive monitors of climate change, they can also be tested against paleoclimate data through hindcast analysis (Rind and Chandler 1991; Crowley 1993). In addition, two recent paleoclimate surprises, one from Greenland and the other from the tropics, have prompted a revisitation of the concept of Holocene climate stability.

In 1993 the journal *Nature* published a commentary on scientific drilling in the Greenland ice sheet that describes the Holocene as climatically "boring" relative to the preceding glacial and interglacial periods (White 1993). This concept evolved from observations that key indicators of climate variability in deep Greenland ice cores show large century-to-millennial-scale

oscillations over most of the past 120,000 years and yet have been almost invariant since about 10,000 years B.P. (Taylor et al. 1993; Grootes et al. 1993; Mayewski et al. 1993, 1994). In one ice core, strata spanning the last interglacial suggested large and abrupt temperature oscillations of 5 to 10°C, a climatic style more similar to the glacial interval than the Holocene. If true, interglacial climates have at least two fundamentally different modes: stable versus unstable. Since the last interglacial was also somewhat warmer than today, the new Greenland findings led to speculation that as greenhouse warming progresses, our present climate system might tip into an unstable mode. A second drill core only thirty kilometers (around eighteen miles) away did not confirm the proposed instability, however, and the ice core community is currently working to develop a clearer understanding of climate during the penultimate interglacial epoch.

These exciting results from Greenland and the ensuing debate over their significance have helped redirect and focus paleoclimate studies over a variety of timescales. The interglacial stability issue has forced us to reexamine what we know about Holocene climate change in different parts of the globe. One key question is the extent to which a single, high-altitude, high-latitude site can serve as a monitor of global or even regional climate change. The large pre-Holocene warm/cold oscillations in the Greenland ice cores have been linked to century-to-millennial-scale changes in ocean circulation and deep water production rates in the North Atlantic (Miller and Kaufman 1990; Bond et al. 1992, 1993). The signal is strong in Greenland because of its proximity to one coupled ocean-atmosphere system that has operated differently during the Holocene relative to glacial times. This system of deep water production and air-sea heat exchange in the North Atlantic is, however, but one of many large-scale climate systems operating simultaneously to produce our global climate. Few today would argue that a stable North Atlantic deep water oscillator precludes Holocene variability in systems such as El Niño, the Southern Oscillation, the Pacific–North American Pattern, or the Asian, American, and African monsoons.

Recent reviews of Holocene paleoclimate research (Jones, Bradley, and Jouzel 1996; Overpeck 1995) suggest surprising instability at low and middle latitudes. Paleohydrological studies provide evidence for sudden, large changes in precipitation patterns (Hodell et al. 1991; Hodell, Curtis, and Brenner 1995; Ely et al. 1993; Knox 1993). New tools have emerged for examining ocean temperatures at timescales of years to decades (e.g., Dunbar and Cole 1993; Druffel et al. 1995); these also show surprisingly large Holocene variability, particularly in the tropics. Until recently, the concept of long-term stability of tropical sea surface temperatures was an entrenched tenet bolstered by the findings of the CLIMAP project that glacial maximum sea surface temperatures throughout most of the tropics were either the same as or slightly cooler (1 to 2°C) than today (CLIMAP Project Members 1976, 1981). This led to suggestions that if tropical temperatures were largely invariant during the last deglacial event, they were unlikely to vary significantly during the Holocene.

The CLIMAP findings were never reconcilable with terrestrial evidence suggesting strong glacial cooling in the tropics. Pollen distribution (Colinvaux 1979; Bush et al. 1990), snow line depression (Clapperton 1987, 1993a, 1993b), tropical ice cores (Thompson et al. 1995), and noble gas distribution in groundwater (Stute et al. 1992, 1995; see also Kerr 1995) all argue for low-latitude cooling of 4 to 12°C during the last glacial interval. Paleotemperature reconstructions using corals suggest that the warm water areas of the Caribbean and western Pacific were also 4 to 6°C cooler (Guilderson, Fairbanks, and Rubenstone 1994; Min et al. 1995). The long-term stability of the tropics is still being hotly debated, but the emerging new picture of glacial age climate includes abrupt changes of 10 to 15°C in parts of the Arctic and a much cooler tropical belt, both in the oceans and on land. This has had two direct effects on Holocene studies: (1) acceptance of larger-than-expected glacial-interglacial change reopens the door for consideration of significant Holocene variability; (2) land-based evidence for cooling and drought may now be reconciled with a cooler glacial age tropical ocean. This finding is in line with recent suggestions about the importance of tropical ocean forcing of global climate (e.g., Graham 1995; Hoerling and Ting 1994) and promotes further development of models of marine impacts on terrestrial climate systems in the Holocene.

In this paper, I briefly describe some of the major components of the global climate system that might be expected to have varied over the past nine thousand years and thus have an impact on development of human cultures. I describe possible forcing mechanisms and use several examples from the paleoclimate literature to address the issue of regular cyclicity versus abrupt change in the Holocene. I conclude with suggestions as to how Holocene climate research might evolve over the next decade and how it might be better integrated into studies of human development. My intent here is not to produce a comprehensive synthesis of current and previous Holocene paleoclimate research but rather to illustrate some examples of new thinking about old problems.

Global Climate Systems

Figures 2.1 through 2.3 show global climatologies of surface temperature, rainfall, and sea-level pressure during January and July. These end-member snapshots provide a view of the annual climate cycle. Because the magnitude of climate forcing at interannual-to-millennial timescales in the Holocene is smaller than the annual cycle of radiative forcing, seasonal climate extremes are sometimes viewed as limit envelopes for longer-period climate variability. These figures also illustrate features of some of the large-scale climate systems that might be expected to vary over timescales of decades to centuries in the Holocene. Over the past several decades, climatologists have identified a large number (more than twenty) of regional or hemispheric climate systems that have characteristic oscillations defined by

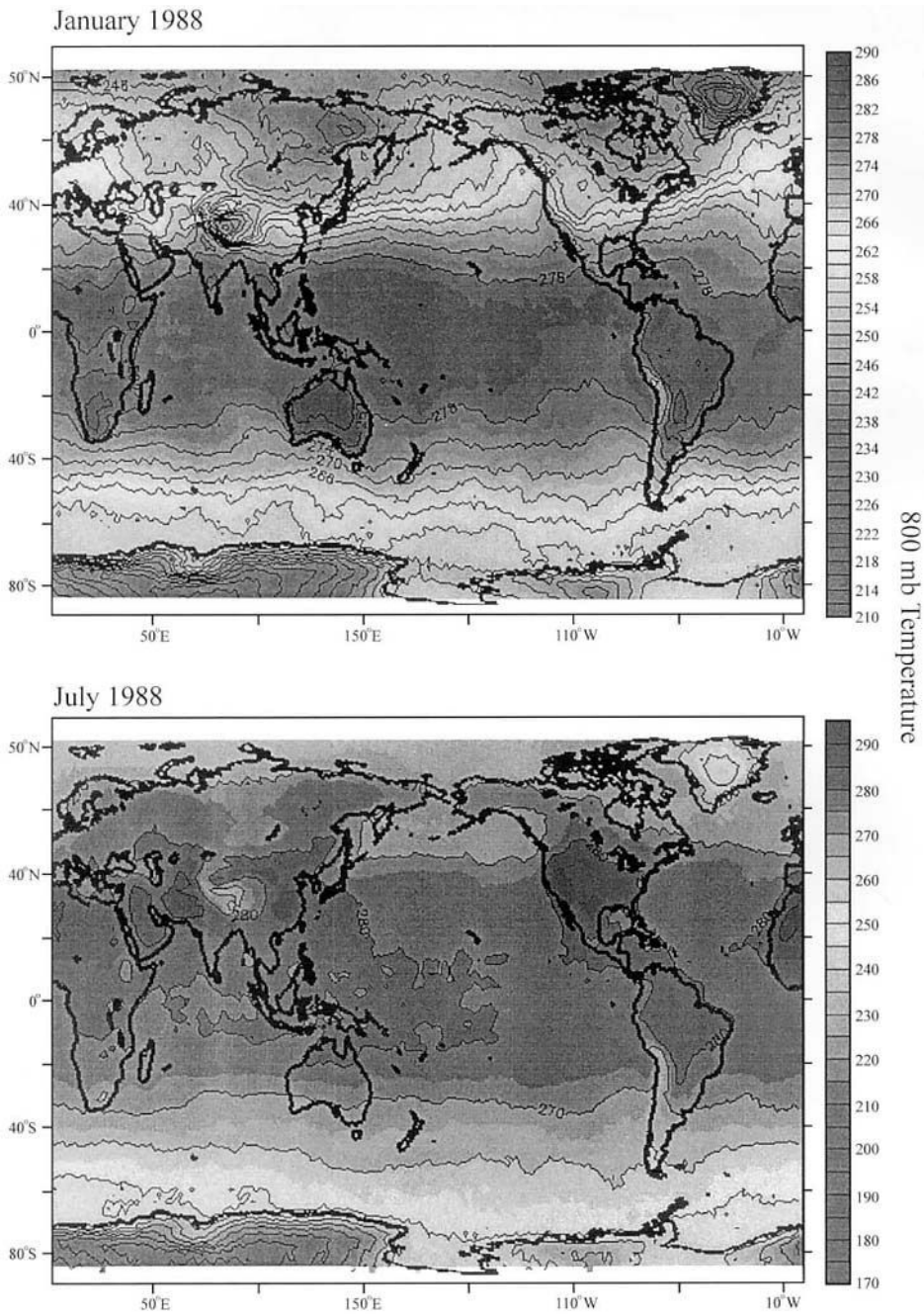


Figure 2.1.
Global surface temperatures, January 1988 and July 1988.
From NOAA/NASA Pathfinder satellite: TOV path C2 benchmark period.

seasonal or interannual progressions in parameters such as rainfall, temperature, or pressure. Many of these systems also include lower-frequency components of variability that are often poorly characterized because of the short duration of the instrumental record and the complexity of interactions

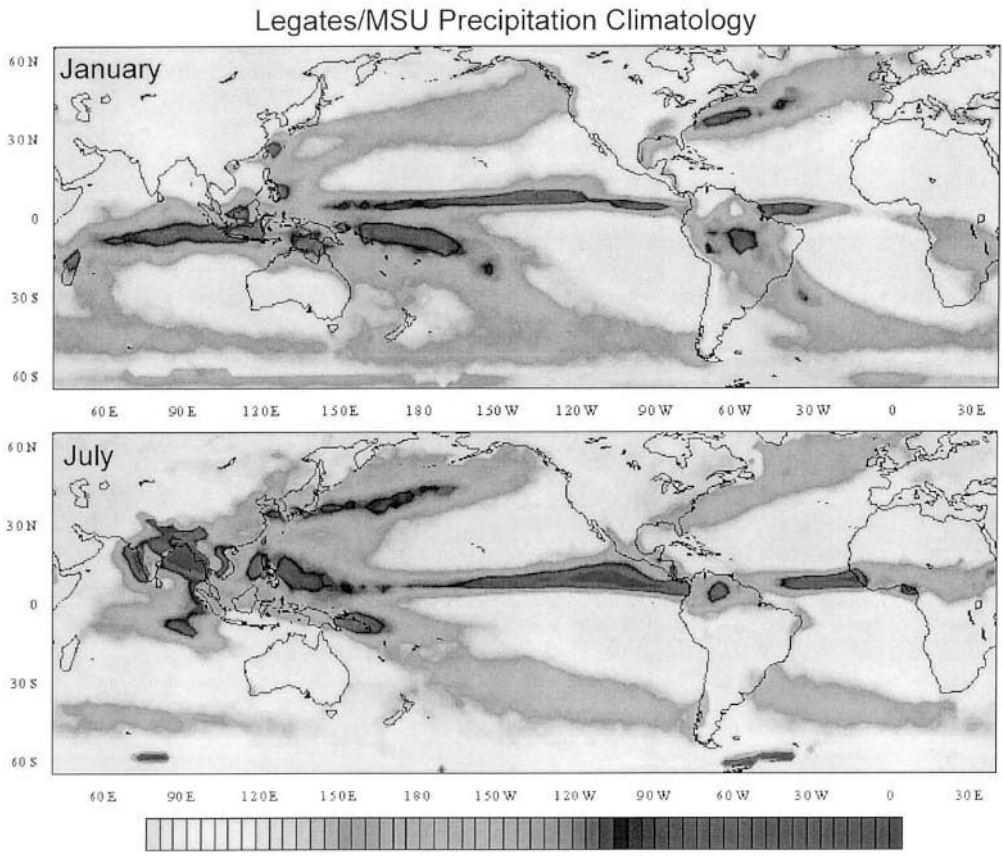


Figure 2.2.
Monthly average global precipitation during January and July 1988.
From Wallace, Mitchell, and Lau 1994, using data in Legates and Willmott 1990 and Spencer 1993.

between different systems. Because the majority of humans have always lived between 30° N and 30° S, three interrelated systems of particular importance for cultural development in the tropics and subtropics are the ENSO, the monsoons, and the Intertropical Convergence Zone (ITCZ).

El Niño/Southern Oscillation

The El Niño/Southern Oscillation phenomenon is responsible for most of the known interannual climate variability in the global tropics and subtropics and is a likely candidate for influencing global climates during the Holocene. Although the term *El Niño* refers specifically to anomalous warming of surface waters in the eastern equatorial Pacific and along the coasts of Peru and Ecuador, such events are manifestations of much larger oscillations in the coupled ocean-atmosphere (Philander 1990; Hastenrath 1991). The Southern Oscillation is a commonly used monitor of the atmospheric component of

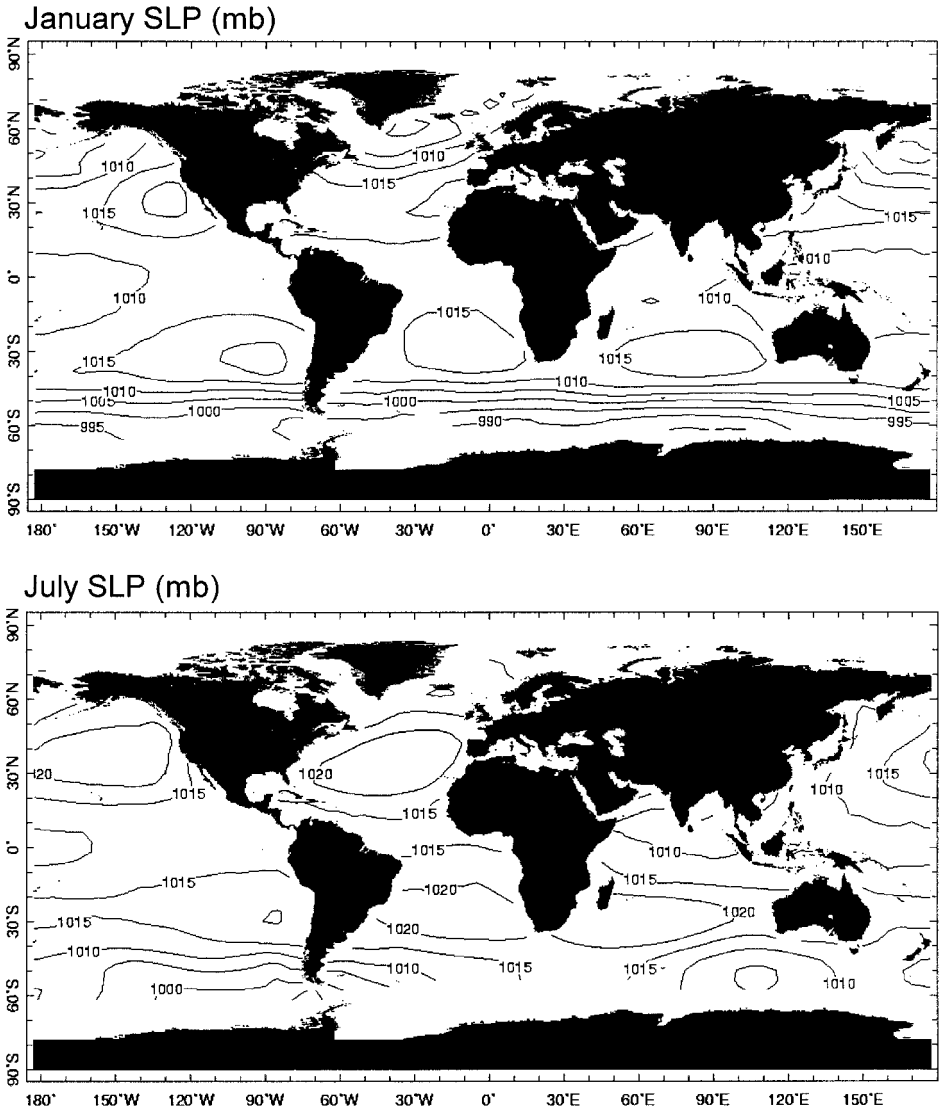


Figure 2.3.
Monthly average sea level pressure (SLP) during January and July. The maps show the mean SLP gridded at a spatial scale resolution of 4 degrees by 5 degrees from data collected over a multidecadal period prior to 1981.
From Esbensen and Kushnir 1981 (documentation at http://pacs.oce.orst.edu/esbensen/tropical/CRI_report_29.html).

this variability and refers to a sea-level pressure seesaw between the south Pacific subtropical high and the Indonesian low (figs. 2.3 and 2.4). Arising from instabilities in the coupled ocean-atmosphere system, warm extremes of ENSO originate in the tropical western Pacific as relaxation or reversal of the easterly trade winds allows warm mixed-layer waters to move eastward. This shift results in a diminished sea surface temperature (SST) gradient along the equator leading to further weakening of the trade winds and sup-

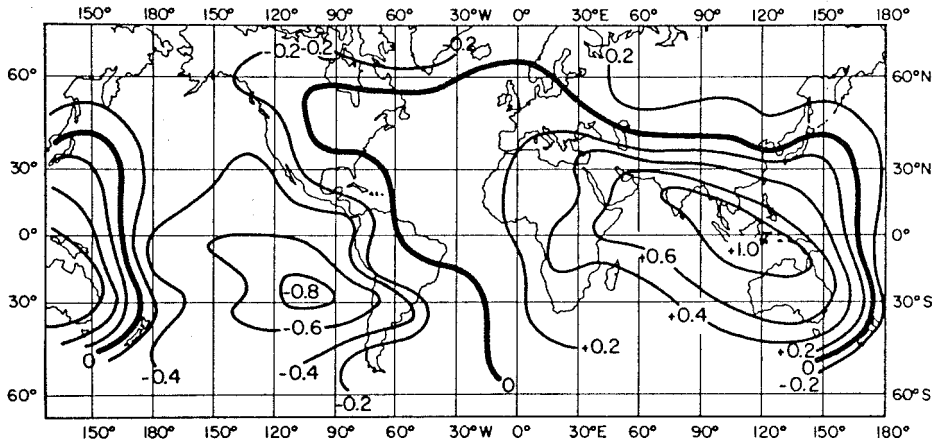
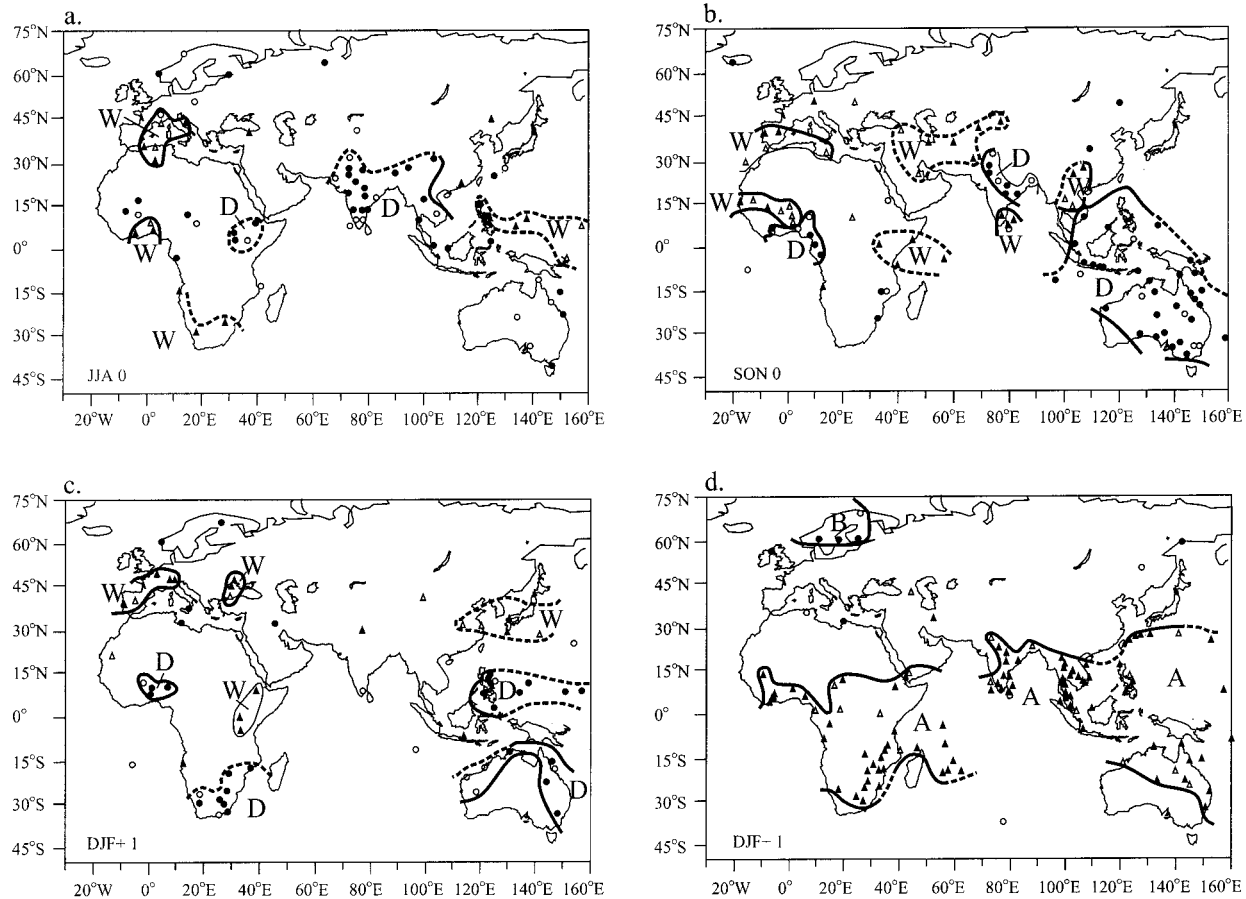


Figure 2.4.
Global distribution of the correlation coefficient between the barometric pressure at Djakarta, Indonesia, and those elsewhere. Note the positive correlations extending over much of Australasia and the Indian Ocean and the negative correlations centered over the southeastern Pacific. This pattern characterizes the pressure seesaw associated with the Southern Oscillation. Interannually, the relative strengths of the Indonesian high and Tahiti low pressure cells varies.
Caption from Enfield 1992; figure from Berlage 1957.

pression of equatorial upwelling. As the east-west SST gradient weakens, atmospheric convection over the western Pacific warm pool is disrupted and the Indonesian low moves eastward along the equator. The effects in the Pacific Basin are drought in Australasia and wet, warm conditions in the central Pacific and parts of the Americas. Although they are less well understood, cool extremes of ENSO are equally important and generally produce climate anomalies with the opposite sign.

Sea-level and upper tropospheric pressure anomalies directly linked to the Southern Oscillation extend far beyond the Pacific Basin and contribute to interannual variability in rainfall and temperature throughout the Americas as well as parts of Asia, Africa, and Europe (figs. 2.5, 2.6; Ropelewski and Halpert 1987; Kiladis and Diaz 1989; Trenberth 1990; Diaz and Kiladis 1992; Halpert and Ropelewski 1992; Hoerling and Ting 1994). Many of these ENSO teleconnections are surprisingly robust, particularly the association of warm events with drought in northeast Brazil and Central America and flooding in the U.S. Gulf Coast, northern Peru, and Argentina (Ropelewski and Halpert 1986; Hastenrath, Castro, and Aceituno 1987; Aceituno 1988; Kiladis and Diaz 1989; Hastenrath 1990). Cane, Eshel, and Buckland (1994) recently showed a strong correlation between sea surface temperatures in the Pacific and grain yields in Zimbabwe, an observation that has already been incorporated into southeast African agricultural planning. Although ENSO-related temperature anomalies also propagate throughout the globe, perturbation of rainfall is likely to have the largest impact on humans through the Holocene. Direct effects include crop failure from drought or flooding. In


a.
JJA 0
b.
SON 0
c.
DJF+ 1
d.
DJF− 1
75°N
60°N
45°N
30°N
15°N
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15°S
30°S
45°S
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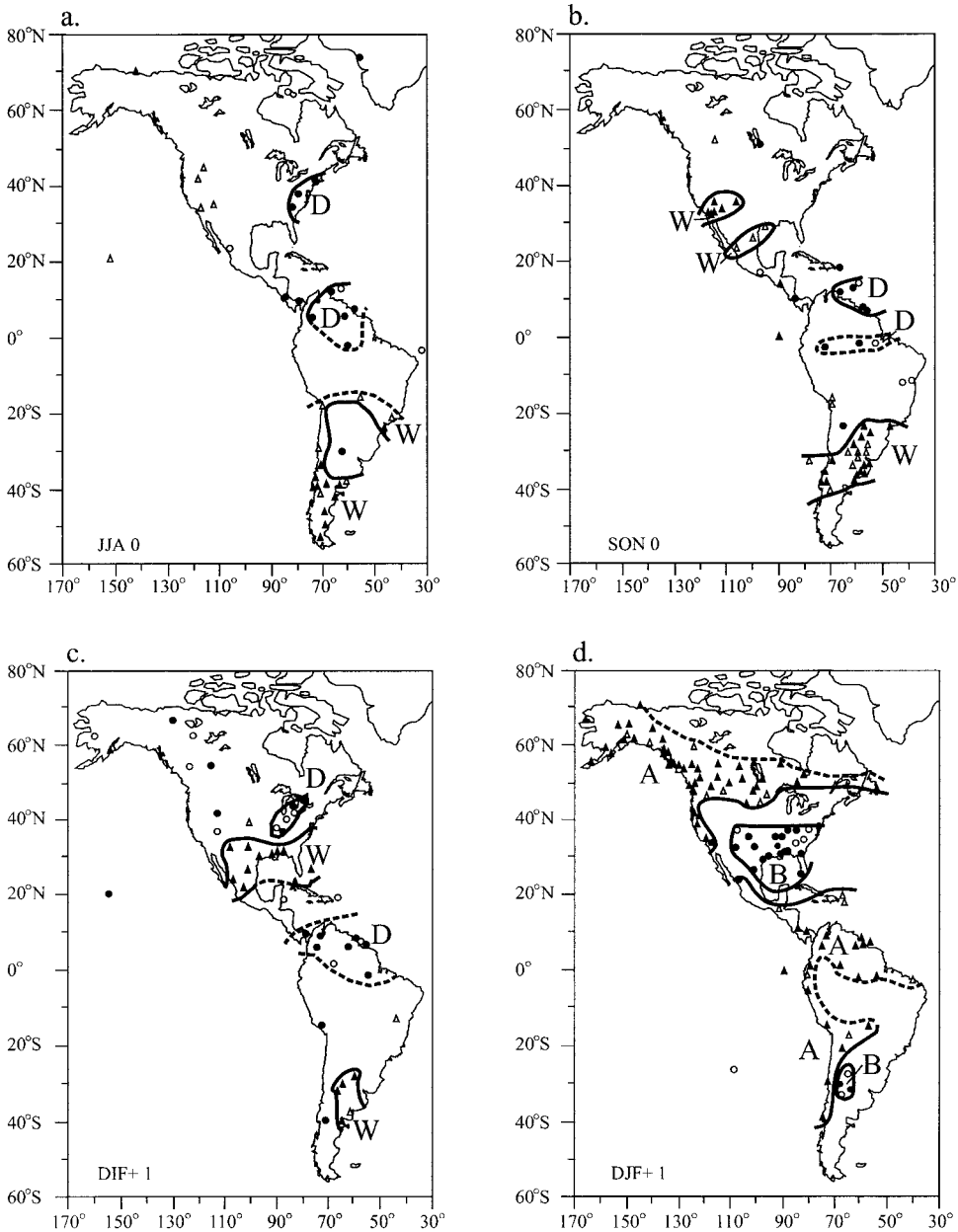


Figure 2.5.
Areas where the composite precipitation anomaly difference between warm and cold ENSO events (warm minus cold) is statistically significant at the 1 percent (solid symbols) or 5 percent (open symbols) level. The anomaly sign indicated in these panels is representative of warm events ("W" for wetter- and "D" for drier-than-normal conditions); the opposite sign is representative of cold events. Old World and New World panels: (a) June–August, (b) September–November, and (c) December–February +1 year seasons. Panel (d) illustrates the corresponding surface temperature anomalies of the DJF +1 year season ("A" stands for above-normal temperature; "B" for below-normal temperature).

From Kiladis and Diaz 1989.

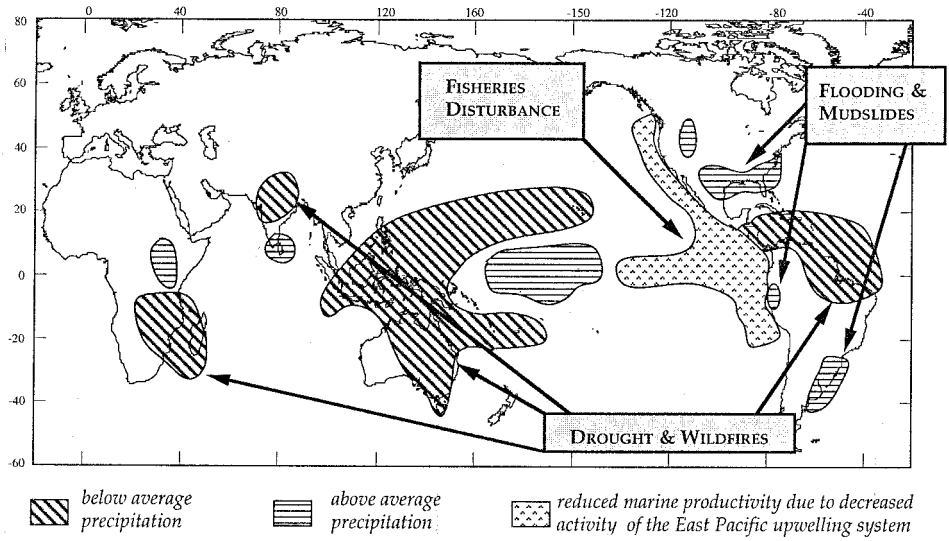


Figure 2.6.
Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation weather system. Disturbance boundaries of fisheries are approximate (see Sharp 1992).

Global effects of El Niño compiled by Thomas Andrews, NOAA Paleoclimatology Program. Northern Peruvian and southern Ecuadorian precipitation anomaly estimated from Wells 1990. Holocene history of the El Niño phenomenon as recorded in flood sediments of northern coastal Peru in Diaz and Markgraf 1992. All other precipitation anomalies based on data from Ropelewski and Halpert 1987.

nonagricultural areas, availability of game and drinking water and the increased possibility of forest fires might be important consequences.

Figures 2.4 through 2.6 show that the extent of ENSO influence is near-global. Is there evidence for long-period climate variability in the Southern Oscillation (SO), and might this be a dominant climate pacemaker for human development in the late Holocene? Analyses of instrumental records and ENSO indices (mostly less than sixty years in length) show that the dominant variance in ENSO occurs over a broad range of periods from three to ten years (Trenberth 1976; Barnett 1991; Rasmusson, Wang, and Ropelewski 1990). A near-biennial component of ENSO (2.2 to 2.8 years) has also been recognized (Rasmusson, Wang, and Ropelewski 1990; Barnett 1991; Ropelewski, Halpert, and Wang 1992), and Lau and Sheu (1988) have postulated a link between fluctuations in the Southern Oscillation and the tropospheric Quasi-Biennial Oscillation. Decadal ENSO variability has recently been recognized (Cooper, Whysall, and Bigg 1989; Trenberth 1990), and some have postulated long-term changes in the relative strength of the Southern Oscillation (Trenberth and Shea 1987; Elliot and Angell 1988). Little is currently known about low-frequency ENSO fluctuations as sufficiently long instrumental records are not available and modeling studies have so far focused on characterization and prediction of ENSO over periods of seasons to several years.

Documentary evidence from Peru and Egypt (Quinn, Neal, and S. E. Antunez 1987; Quinn 1992; Quinn and Neal 1992) suggests that ENSO warm-mode recurrence intervals also vary over multidecadal to century time-scales. The Nile flood record extends back nearly fourteen hundred years (Hassan 1981; Fairbridge 1984; Quinn 1992) and offers an opportunity for analysis of low-frequency variability in the Southern Oscillation. Quinn reports that recurrence intervals between weak Nile River floods (linked to ENSO warm events) range from thirteen years between A.D. 1000—1290 to as short as three years during the 1700s and 1800s. Diaz and Pulwarty (1992) and Anderson (1992b) cite statistical evidence for significant concentrations of variance in Quinn's ENSO reconstructions at periods of approximately ninety years and forty-six years (fig. 2.7). Weaker periodicity is observed at periods of about thirty and twenty years. A characteristic feature of the Quinn spectrum is that the concentration of variance at these longer periods is time transgressive. For example, during the past four hundred years, forty- to fifty-year periodicity is strongest during the 1600s and again since 1790 (Diaz and Pulwarty 1992). Variance at an approximately ninety-year period is strongest between 1000 and 1400, a time of overall infrequent Nile flood events (Anderson 1992b). These analyses suggest that low-frequency manifestations of ENSO extend beyond simple variability in the recurrence interval of ENSO cool or warm modes.

Further illustration of ENSO variability is provided by analyses of reef corals from the tropical ocean. Corals produce annual growth bands that can be used to establish chronology (much like tree rings) and record variations in seawater temperature and salinity via chemical and isotopic components incorporated into the coral skeleton (Dunbar and Cole 1993). A 367-year isotopic reconstruction of surface ocean temperature at Galápagos provides an annual resolution record of ENSO variability in the eastern Pacific (fig. 2.8; Dunbar et al. 1994). The annual $\delta^{18}O$ series shows low temperatures during the early 1600s and early 1800s; warm, stable conditions during the 1700s; and a long-term cooling trend of about 1°C since the 1700s. Oscillations within the ENSO frequency band (three to ten years) dominate the $\delta^{18}O$ time series, accounting for more than 28 percent of the total variance. Additional significant oscillations occur at periods of eleven, seventeen, twenty-two, and thirty-four years. The dominant oscillatory periods, both within the ENSO and interdecadal frequency bands, shift from longer to shorter periods (moving forward in time) in the mid-1700s and again in the mid-1800s (fig. 2.8), apparently reflecting large-scale reorganizations within the tropical ocean-atmosphere system. This analysis suggests a succession of century-scale intervals, or modes, each defined by a characteristic variance spectrum and separated by decade-scale periods of rapid change, or mode shifts. The fact that our intensive process studies of ENSO and its teleconnections have occurred within a single mode during the past fifteen years means that our instrumental understanding of this system underestimates its true variability and extratropical response in the late Holocene.

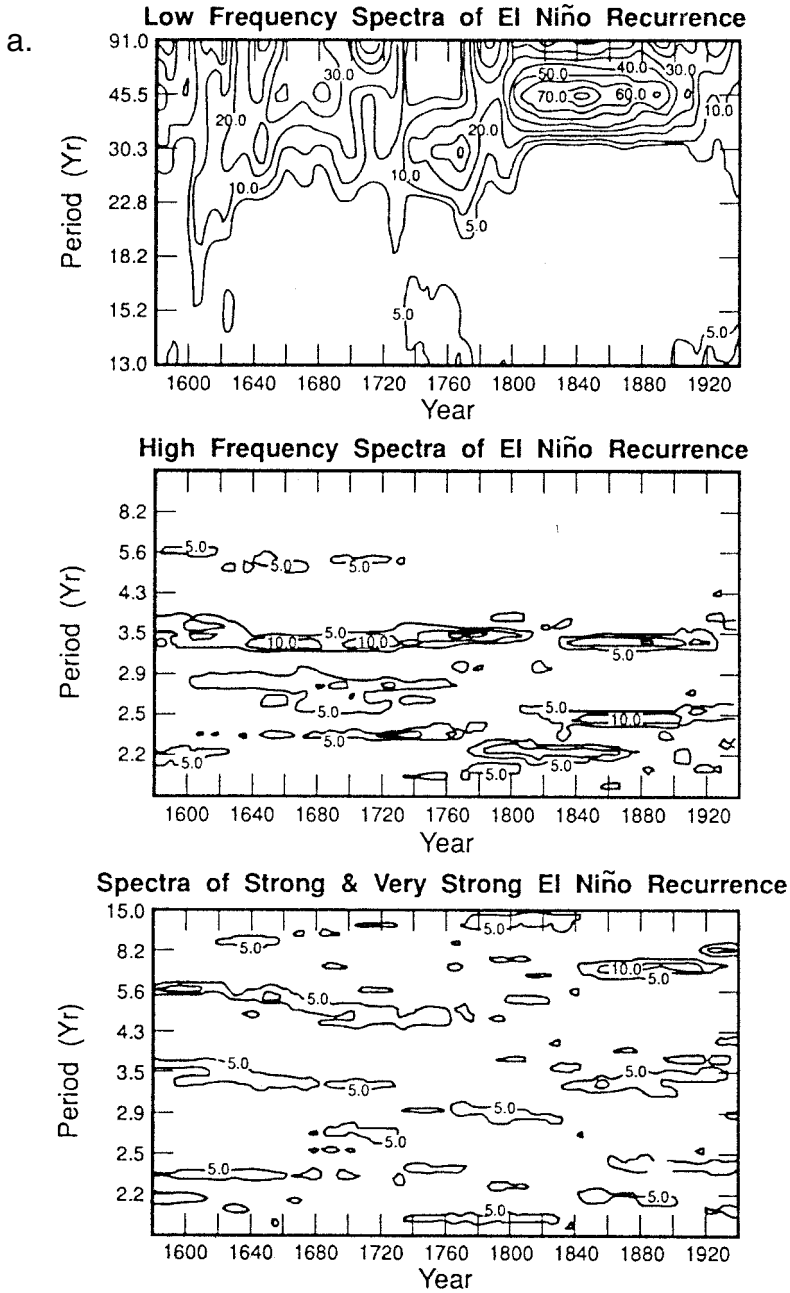
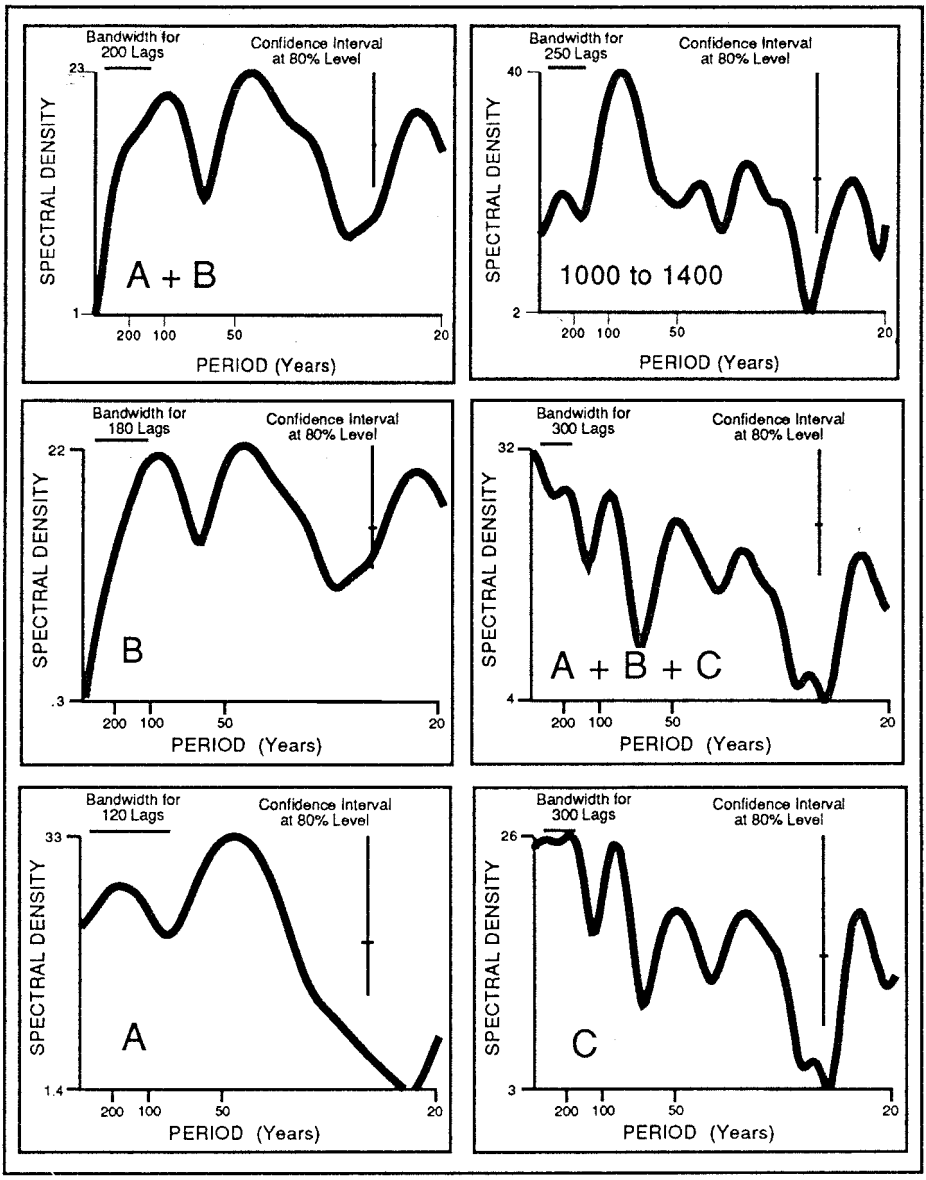


Figure 2.7.
(a) Moving ninety-one-year FFT (fast Fourier transform) spectra of moderate and stronger El Niño recurrence, shown as contours of percentage of total variance explained by different spectral lines. Input values are nineteen-year moving averages of event occurrence from 1525–1988 for low-pass and high-pass (residuals) filtered values (top and middle panels) and high-pass filtered values (bottom panel) calculated from a thirty-one-year moving average of the recurrence of strong and very strong El Niño events only.

Figure from Diaz and Pulwarty 1992, who used the data of Quinn 1992.

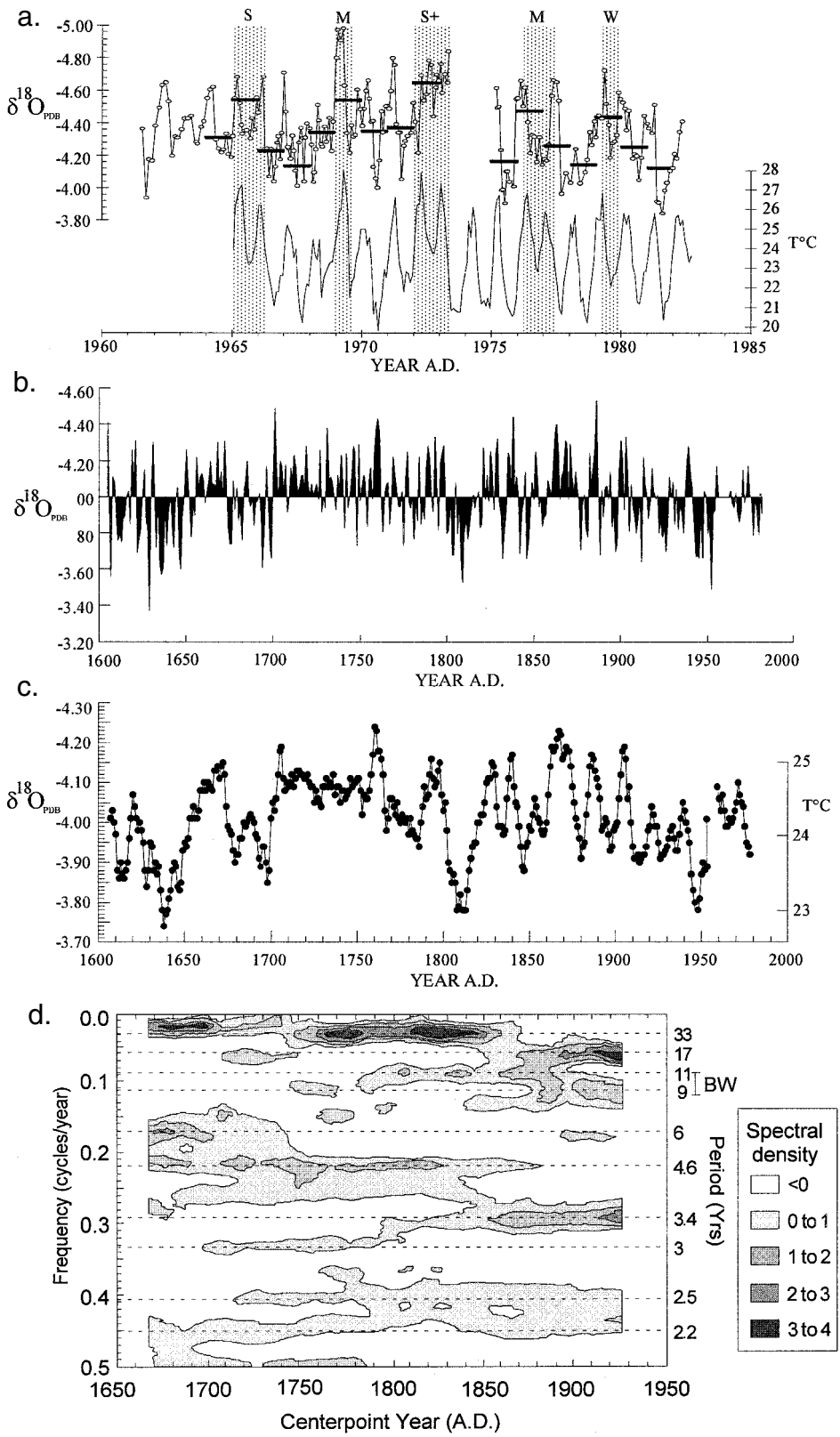
b.



(b) Log power spectral density for segments of the El Niño time series reconstructed in Quinn 1992. Data converted to events per year by applying a linear nine-term running filter to unranked series. Segment A: all events, 1800–1984; segment B, strong events, 1525–1800; segment C, Nile flood SO reconstruction A.D. 622–1525.]

From Anderson 1992b.

The timescales over which ENSO variance has been demonstrated are clearly important for human adaptation to climate change and the development of a social memory of major events. Strong forty-to-fifty- and ninety-year periodicity in Southern Oscillation teleconnections (e.g., figs. 2.5, 2.6) must have an impact on record-keeping societies that differs from the effects


a.
S
M
S+
M
W
δ18OPDB
-5.00
-4.80
-4.60
-4.40
-4.20
-4.00
-3.80
28
27
26
25
24
23
22
21
20
T°C
1960
1965
1970
1975
1980
1985
YEAR A.D.
b.
δ18OPDB
-4.60
-4.40
-4.20
-3.60
-3.40
-3.20
1600
1650
1700
1750
1800
1850
1900
1950
2000
YEAR A.D.
c.
δ18OPDB
-4.30
-4.20
-4.10
-4.00
-3.90
-3.80
-3.70
25
24
23
T°C
1600
1650
1700
1750
1800
1850
1900
1950
2000
YEAR A.D.
d.
Frequency (cycles/year)
0.0
0.1
0.2
0.3
0.4
0.5
33
17
11
9
BW
6
4.6
3.4
3
2.5
2.2
Period (Yrs)
Spectral density
<0
0 to 1
1 to 2
2 to 3
3 to 4
1650
1700
1750
1800
1850
1900
1950
Centerpoint Year (A.D.)

of subdecadal variability that can be observed by a single generation. Do we see evidence for recognition of these lower-frequency changes in the archaeological/anthropological records? Presumably, the areas with the strongest teleconnection patterns are most likely to provide evidence of societal adaptation to periodic change in the ENSO system.

Major uncertainties remain in resolving the link between ENSO and global climate anomalies at decade-to-century periods. Analyses of instrumental data show that successive ENSO events produce different temperature anomalies in the central Pacific (Fu, Diaz, and Fletcher 1986). Spatial differences in sea surface temperature anomalies between different ENSO warm phases lead to altered patterns of extratropical teleconnections (Hoerling and Ting 1994). In fact, without long-term tropical records for comparison with the extratropical response, we don't yet know how much low-frequency variability observed in Holocene paleoclimate records results from fundamental changes in the strength and frequency of ENSO versus altered patterns of teleconnection. We also know very little about interactions between ENSO and other climate systems. Trenberth and Hurrell (1994) stress the overall importance of climatic forcing by tropical ocean temperatures and ENSO but hypothesize that feedbacks in the extratropics emphasize the decadal component of variability.

Nevertheless, as Enfield (1992) points out, ENSO is the most energetic climate phenomenon we know of at interannual timescales. Although other systems may manifest as stronger responses locally (the monsoon in India, for example), even in these areas ENSO may provide background variability

Figure 2.8. *(facing page)*
(a) Subannual (open circles) and annual (horizontal) $\delta^{18}O$ values along a twenty-year transect from a specimen of *Pavona gigantea* from Urvina Bay, Galápagos Islands. Subannual samples were collected by drilling; annual samples were collected by cutting out an entire growth band. Also shown is monthly average SST recorded at the Darwin Station in Academy Bay and the relative strength of the five ENSO events that occurred during the period of record. (b) Annual $\delta^{18}O$ values of growth bands from a specimen of *Pavona clavus* from Urvina Bay. Samples were run in duplicate or triplicate, the mean standard deviation is 0.07 parts per thousand. (c) Same data as in (b) presented as a five-point moving average to filter out high-frequency variability. Conversion of the isotopic results to absolute paleotemperature is complicated by possible variations in the $\delta^{18}O$ of local seawater. Because there is no instrumental SST or salinity time series available at Urvina Bay, I have assumed there is no long-term change in seawater $\delta^{18}O$ and used the *P. gigantea* $\delta^{18}O$ / Academy Bay SST correlation and known cross-calibration between *P. clavus* and *P. gigantea* to assign a working estimate of temperature variability. (d) Evolutionary spectral diagram of the Urvina Bay annual $\delta^{18}O$ record shown in (b) above. Shaded regions correspond to frequencies at which significant variance occurs. The diagram contours spectral density as a function of time and frequency (from spectral analysis) of a series of 120-year-long segments, each offset by ten years. A low-resolution spectra (5 lags) was subtracted from the high-resolution spectra (40 lags) for each time slice before the matrix was assembled for contouring.

From Dunbar et al. 1994.

that amplifies or attenuates climate anomalies. ENSO has influenced climate in both the tropics and extratropics since at least the mid-Holocene and produces quasi-periodic climate anomalies. New evidence is emerging from northwestern South America that ENSO oscillations did not exist as recently as five thousand years ago (Sandweiss et al. 1996). These authors propose an extended period of stable, wet climate suggestive of constant warm-mode conditions in areas characterized today by episodic and infrequent rainfall. If validated by further research, this scenario may represent another possible mode of climate variability with global ramifications that may have impacted emerging cultures in the mid-Holocene.

The Monsoons and Intertropical Convergence Zone

Although the monsoons have traditionally been defined on the basis of complete large-scale seasonal reversals of surface winds (Ramage 1971; Hastenrath 1991), their most important paleoclimatic consequence is variability in tropical and subtropical rainfall. In some areas such as central India, more than 90 percent of annual rainfall is delivered during the summer monsoon. The strongest reversals occur in Asia as well as East and West Africa; however, weaker and more variable wind reversals produce monsoonal regimes in parts of Central America, South America, and Australasia (fig. 2.9). The monsoons develop as the equatorial low-pressure trough either moves to or dissipates and re-forms at northerly and southerly positions with the seasons. The trough and associated subtropical anticyclones are displaced

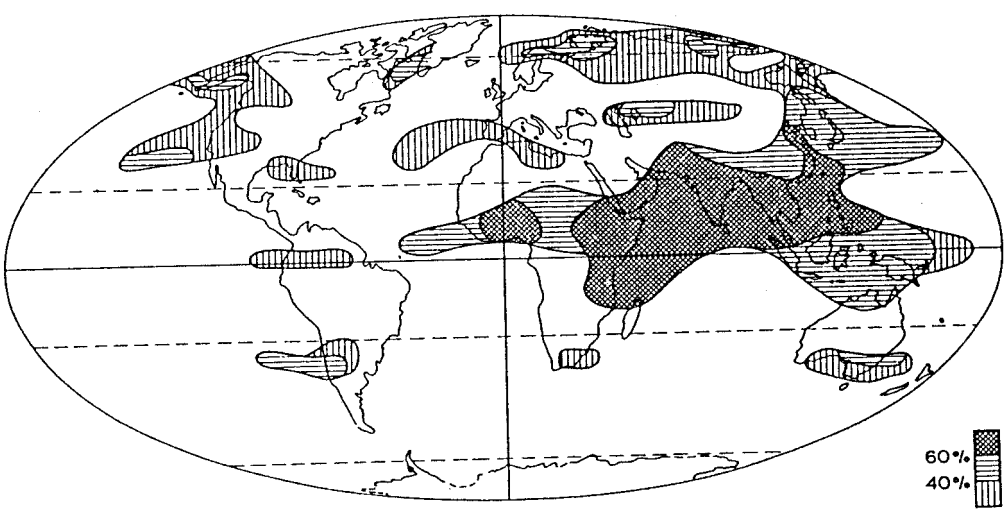


Figure 2.9.
Regions experiencing a seasonal surface wind shift of at least 120°, showing the percentage frequency of the prevailing octant.
After Chromov; adapted from Flohn 1960.

northward during the northern summer as a result of seasonal changes in radiative forcing. This forcing is at times enhanced by the effects of land masses and may also be influenced by upper tropospheric winds. Seasonal variations in rainfall linked to the monsoon are visible in figure 2.2.

Modern agriculture and commerce in India are heavily dependent on the arrival time and strength of the summer monsoon, and it seems likely that such dependency has been maintained for many centuries. Instrumental and historical data document multidecadal region-specific variability in the strength of the Indian monsoon. Over most of India, the periods 1871–1900 and 1930–1960 were unusually wet relative to 1901–1930 and 1961–1990 (Sontakke, Pant, and Singh 1993; Parthasarathy, Munot, and Kothawale 1992). In fact, rainfall in many areas of Southeast Asia has decreased over the past several decades, possibly the direct result of recent frequent/intense El Niños (Nicholls et al. 1996). Northwestern India has experienced increasing amounts of rainfall since the 1900s, although this increase has been attributed in part to a coincident increase in the amount of land under irrigation (Pant and Hisgane 1988). Links between Eurasian and Himalayan snow cover and both the onset date (Dey and Kathuria 1986) and withdrawal date (Dey, Kathuria, and Bhanu Kumar 1985) as well as intensity (Barnett et al. 1989; Vernekar, Zhou, and Shukla 1995) of the Indian monsoon have also been proposed.

Indian monsoon rainfall is strongly correlated with the Southern Oscillation, as was first pointed out by Walker (1923) and Walker and Bliss (1930). Of the forty-four El Niños documented by Quinn and Neal (1992) in the eastern Pacific between A.D. 1824 and 1972, 84 percent (thirty-seven) coincided with years of anomalously low Indian summer monsoon rainfall (Quinn 1992). A similar pattern of coincident drought is also seen in Australia, Indonesia, and parts of East Africa (Whetton and Rutherford 1994).

In most of the tropics, summer monsoon rains are triggered by the annual northward expansion of the Intertropical Convergence Zone (ITCZ). The ITCZ coincides with the near-equatorial low-pressure trough and marks the marine confluence between the Northern and Southern Hemisphere trade winds (see Philander 1990 and Rasmussen and Arkin 1993 for recent reviews). In fact, over 40 percent of global precipitation falls within fifteen degrees of the equator, and most of this is associated with the marine convergence zones (Rasmusson and Arkin 1993). ITCZ precipitation in the eastern Pacific ranges up to 560 centimeters per year, more than anywhere else on earth except for isolated regions influenced by orographic forcing (fig. 2.2). The northern and southern boundaries of the ITCZ are sharp, and Philander (1990) has suggested that even small variations in the past mean position and range of the ITCZ could significantly influence rainfall distribution in the tropics and subtropics. The areas that might be influenced by past changes in the ITCZ are those adjacent to and between the seasonal extreme positions of the ITCZ shown in figure 2.10.

Sea surface temperatures in part control the position of the ITCZ, and in

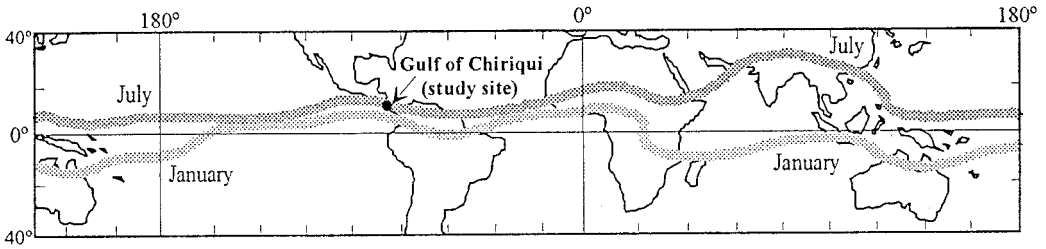


Figure 2.10.
Schematic representation of the average position of the Intertropical Convergence Zone (ITCZ) in January and July. The ITCZ occupies its most northerly position during the Northern Hemisphere summer. Arrow marks the position of the coral time series shown in figure 2.11.
From Linsley et al. 1994.

areas with relatively small land mass effects (e.g., Central America), marine influences may be the primary control on terrestrial monsoon characteristics. The SST threshold for the onset of tropical atmospheric convection is around 27°C (Palmer and Mansfield 1984; Gadgil, Joseph, and Joshi 1984; Graham and Barnett 1987), and the ITCZ is correspondingly anchored to warm water regions. With such a convective threshold, we might expect the ITCZ system to be significantly affected if tropical SSTs drop by as little as 1°C. Aridification in parts of the Amazon Basin during the late glacial stage (Colinvaux 1979; Clapperton 1993a, 1993b) is consistent with a reduction in tropical convection over a 4 to 6°C cooler ocean (Guilderson, Fairbanks, and Rubenstone 1994). Smaller yet still significant effects might be expected during the Holocene.

There are few long-term records of variability of the ITCZ. Monthly-resolution isotopic analyses of a coral core recovered from coastal Panama provide the first reconstruction of variability in the eastern Pacific ITCZ from 1707 to 1984 (fig. 2.11; Linsley et al. 1994). The annual cycle in rainfall, produced by the seasonal north-south movement of the ITCZ, is the dominant feature of this isotopic time series, accounting for 51 percent of the total variance. The strength of the annual cycle varies and is strongest from the late 1700s through the mid-1800s and again since around A.D. 1900. The Central American monsoon system thus demonstrates significant century-scale variability independent of long-term trends in the amount of rainfall. After the annual cycle, the next most significant oscillations have a period of around nine years, a frequency also apparent in long instrumental rainfall records from Panama. Other significant interannual $\delta^{18}O$ oscillations occur at periods near 27–30, 5–6, 18.9, 11–13, and 3.1 years (listed in order of decreasing variance). As with the Galápagos coral record, we see evidence for a shift in the periods at which variance is concentrated during the mid-1800s. This general pattern of century-scale mode shifts and multidecadal variance in ITCZ rainfall has not yet been demonstrated further back in the Holocene, but it seems reasonable to consider this style of variability rather than a stationary system as the normal climate regime.

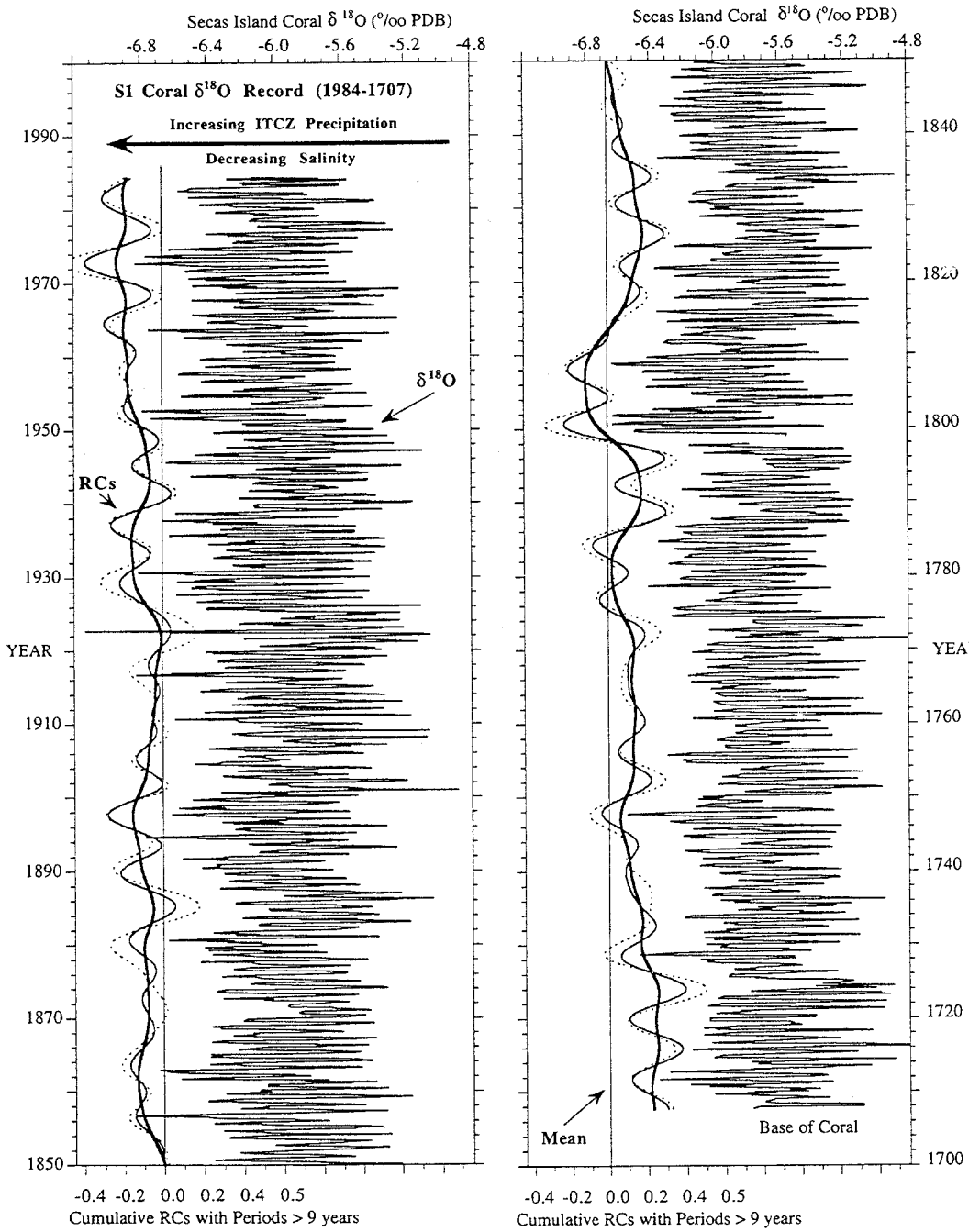


Figure 2.11.
Secas Island (Panama) monthly coral $\delta^{18}O$ data showing pronounced seasonal and decade-scale variability. The leftmost curves in each panel are cumulative reconstructed components (RCs) with periods more than nine years from Singular Spectrum Analysis. The RCs serve to highlight lower-frequency variability.
From Linsley et al. 1994.

North Pacific and North Atlantic Oscillations

Walker (1924) recognized three large-scale atmospheric oscillations defined as surface pressure seesaws: the Southern Oscillation, the North Pacific Oscillation, and the North Atlantic Oscillation. The North Atlantic Oscillation (NAO) describes the relative strengths of the Azores High and Icelandic Low (fig. 2.3). The state of this system controls the strength and position of the poleward pressure gradient and thus directly influences the position and strength of the westerly winds and storm tracks over Europe (Lamb and Peppler 1991). The influence of this system extends far beyond the Azores and Iceland. Hurrell (1995, 1996) estimates that the NAO accounts for more than 75 percent of the interannual variance in winter sea-level pressure between 20 to 80° N and 90° W to 40° E. Periods of low SST in the North Atlantic correspond with periods when the pressure differential between Iceland and the Azores grows stronger, and lead to an overall intensification of atmospheric circulation (Bjerknes 1964). During such periods of strong sea-level pressure gradients, northern Europe experiences cold winters and enhanced precipitation, while southern Europe experiences warm winters (van Loon and Rogers 1978; Hurrell 1995). During periods when the Iceland/Azores pressure gradient weakens, the westerlies also weaken and shift southward, causing northern Europe to be warmer and dryer. In the eastern United States, a low North Atlantic Oscillation index is associated with increased storminess and decreased winter temperatures (Dickson and Namias 1976; Dickson et al. 1997). The current positive (high) phase of the NAO has been linked to decade-long dry conditions in the Mediterranean and wet conditions in Scandinavia (Hurrell 1995).

The North Atlantic Oscillation exhibits strong decadal variability (Deser and Blackmon 1993; Hansen and Bezdek 1996). Besides decade-scale variability, long-term records of the NAO demonstrate a century-long cycle in the strength of the North Atlantic westerlies (IPCC 1990). Long paleoclimate records from Bermuda corals (Pätzold and Wefer 1992) and Greenland ice cores (Taylor et al. 1993) provide evidence for persistent multidecadal (fifteen- to fifty-year) oscillations in this system. Walker and Bliss (1932) concluded that the connection between the Southern Oscillation and the North Atlantic Oscillation is negligible. On the other hand, these authors did suggest a link between the SO and the North Pacific Oscillation (NPO) wherein the SO can influence the NPO with lead times ranging from zero to six months (Hastenrath 1991).

The NPO refers to a surface pressure dipole between the North Pacific High and the Aleutian Low. Similar to the situation in the North Atlantic, variability in the strength of the dipole has been linked to zonal windflow and large temperature and precipitation anomalies downstream in North America. The NPO defines a stationary system; a related index is the Pacific–North America Pattern (PNA). The PNA is also based on the surface pressure field but in this case monitors large-scale wave phenomena propagating

across the Pacific into North America. When the PNA index is positive (corresponding to a deepening of the Aleutian Low), there is a tendency for persistent wintertime ridging over western North America that reduces snowpacks (Cayan 1996). Associated with this ridging are broad areas of warm temperature in northwestern Canada, increased rainfall in the Gulf of Alaska, and southward-displaced storm tracks that produce anomalously wet conditions across the southwestern United States (Cayan and Peterson 1989). Compilations of both instrumental and paleoclimatic evidence suggest multidecadal periodicity in the PNA; a period near forty years appears particularly prominent (T. Baumgartner, pers. comm., 1995). During the later part of this century, positive PNA indices were linked to El Niño conditions in the tropical Pacific. It is unclear, however, how robust this relationship is for long periods of time (Trenberth 1990; Trenberth and Hurrell 1994; Anderson and Dunbar 1995).

Atlantic Dipole and the Antarctic Circumpolar Wave

In general, interannual variability in sea surface temperature and sea-level pressure in the equatorial and midlatitude Atlantic is less than in the Pacific Basin. However, at decadal timescales, the subtropical Atlantic Ocean experiences gradual warming and cooling that produces a dipole pattern in SST with opposite signs in the Northern and Southern hemispheres (Hastenrath and Heller 1977; Palmer 1986). Since sea-level pressures vary with the temperature of the underlying water, a warm South Atlantic and cool North Atlantic produces a southward pressure gradient at the equator and a southward shift of the ITCZ by up to several hundred kilometers (Hastenrath and Greischar 1993). This leads to droughts in northeastern Brazil and similar north-south shifts in rainfall within the Sahel region of West Africa (Folland, Palmer, and Parker 1986). There are currently no multicentury reconstructions of Atlantic dipole variability; however, there is no a priori reason to suspect that this system has not provided a strong decadal pulse to rainfall and drought events in the subtropical Atlantic region.

The Antarctic Circumpolar Wave (ACW) is a newly discovered phenomenon (White and Peterson 1996; Jacobs and Mitchell 1996) that refers to regular oscillations in Southern Ocean SST, meridional wind, sea-level pressure, and sea ice extent. Anomalies in these parameters extend over spatial scales of two to five thousand kilometers (around twelve hundred to three thousand miles) and slowly move eastward around the Antarctic continent, completing a circuit within five to ten years. Over the short period for which instrumental data is available, the magnitude of the anomalies is greatest in the Pacific sector (Peterson and White 1998). The wave pattern produces an SST dipole in the South Atlantic that influences rainfall in southern Brazil and Argentina. Other teleconnections between the ACW and the southern midlatitudes are also likely but have not yet been examined. Peterson and White

(1998) suggested that the ACW links ENSO variability between the Pacific, Atlantic, and Indian basins, via the propagation of ENSO SST anomalies southward from the western subtropical Pacific into the Southern Ocean. In this fashion, Pacific ENSO anomalies move slowly within the ACW and impact the Atlantic and Indian oceans four to eight years later.

Causes of Holocene Climate Variability

The nature of specific causal mechanisms controls whether they are likely to have an oscillatory versus steplike influence on climate. Oscillatory climate influences are arguably the easier of the two for humans to deal with, with the proviso that societies have some form of record keeping and can adopt a successful strategy for dealing with rhythmic changes. Here I briefly list the possible mechanisms for climate change and offer views on the state of knowledge regarding their impact. Observed and inferred climate change during the past several millennia is compatible with one or more of the following causes (Rind and Overpeck 1993; Crowley and Kim 1993; Overpeck 1995).

Inherent Variability in the Atmosphere

Inherent variability (such as the Southern Oscillation and other phenomena described above) is likely to produce cyclical variability throughout the Holocene with periods ranging from around two to at least one hundred years. The IPCC reports (1994, 1996) demonstrate that ENSO events can produce global-scale warming on the order of several tenths of a degree, but more important consequences are region-specific rainfall and temperature anomalies.

Inherent or Forced Variability in Ocean Processes

The paradigm here is variability in the rate of North Atlantic deep water (NADW) production. During the last glacial period, NADW production was severely curtailed on century-to-millennial timescales, causing large temperature anomalies (up to 15°C) in some North Atlantic regions. Feedbacks involving high-latitude albedo and rapid deflation of local ice sheets enhanced the magnitude of these events. Such feedbacks do not appear possible during most of the Holocene, but other regulatory mechanisms such as ocean salinity may operate. For example, the heavy rains over the central United States during the summer of 1993 produced a low-salinity lens in the Gulf of Mexico (Walker et al. 1994) that eventually merged into the Gulf Stream (Lee et al. 1994), where it was carried north toward the source regions for NADW. Oceanographers have suggested that a small decline in NADW production may result, possibly causing North Atlantic cooling. Such a mechanism may well have operated through the Holocene, introducing a quasi-periodic climate signal focused in the North Atlantic. In fact, climate

circulation models have exhibited natural variability in the production rate of NADW with periods of roughly fifty years (Manabe and Stouffer 1988; Delworth, Manabe, and Stouffer 1993).

Solar Variability

Solar output has received renewed attention as a climate forcing mechanism at decadal timescales. Anderson (1992a, 1992b) and Dunbar et al. (1994) review evidence for solar cycle periodicities in some paleoclimate records. Many annual resolution data sets show significant spectral variance at periods of eleven and/or twenty-two years, but it is not yet clear how forcing at this short timescale actually occurs, especially in marine settings. Recent analyses of solar output variability based on changes in sunspots and solar faculae (e.g., solar bright spots; see Lean, Skumanich, and White 1992; Hoyt and Schatten 1993; Lean 1996) argue for an increase in solar irradiance over the past hundred and fifty years of about 0.2 to 0.4 percent. These numbers are larger than previously thought, leading some to speculate that global warming of the past century is more the result of solar variability than an increase in the concentration of greenhouse gases (Jastrow, Nierenberg, and Seitz 1992). The verdict on solar forcing is not in yet, but it may be responsible for as much as 0.5 to 1.5°C of global average temperature variability during the Holocene (Rind and Lean 1994) and would most likely produce a rhythmic signal with periods in the range of ten to a hundred years. General Circulation Models (GCMs), however, forced by realistic estimates of solar variability during the past four hundred years show dramatically heterogeneous climate responses around the globe (Rind and Overpeck 1993). Apparently, advective processes dominate over radiative cooling/warming, resulting in warm/cool anomalies on the order of more or less 1°C with spatial scales of roughly one thousand kilometers.

Volcanic Aerosol Loading

Large volcanoes that introduce sulfur aerosols into the atmosphere have pronounced short-term climate effects. Following the 1991 eruption of Mount Pinatubo, clear-sky irradiance levels at the surface were reduced by about 3 percent for several months (Dutton and Christy 1992), leading to global cooling of 1 to 2°C through 1994 (IPCC 1996). Robock and Mao (1992) suggest that basal stratospheric temperatures increase as a result of volcanic aerosol loading, influencing zonal winds and resulting in warmer winter temperatures at the surface. Key variables that control the magnitude of a volcano's influence on climate include latitude, eruptive height, and magnitude of aerosols ejected. Overall, the distribution of volcanic activity during the Holocene appears to be random. Extremely large events may occur every hundred to thousand years that influence global temperatures by as much as 4 to 6°C for a period of several years. Eruptions occurring within several

years of each other may lead to an extended decade-scale anomaly. The volcanic influence on climate would appear as episodes rather than as periodic phenomena and may thus pose special problems for humans living in areas with a strong rainfall or temperature response.

Earth Orbital (Milankovitch) Variations

Variations in orbital parameters are known to affect significantly the distribution of solar irradiance reaching the earth (e.g., Berger et al. 1984). In particular, the precessional components, with a composite period of about twenty-six thousand years, have certainly influenced seasonality and latitudinal distribution of solar insolation through the Holocene. Over timescales of thousands of years, precessional changes in summer insolation over Africa and Asia are considered major forcing factors for the Asian and African monsoons because of the differential response of land and sea to solar heating (Kutzbach 1981). For example, between about nine thousand years ago and the present, the time of perihelion (the day the earth is at its closest approach to the sun) has changed from July to January. Thus both seasonality and summer insolation were greatest in the Northern Hemisphere during the early to middle Holocene and have lessened ever since. Kutzbach and Webb (1993) link increased summer insolation at 9000 B.P. to enhanced monsoonal circulation over North Africa and Eurasia. In fact, based on data-model comparisons for climatic changes between sequential three-thousand-year time slices since the last glacial maximum, Webb et al. (1993) report that precessional changes in solar insolation and the configuration of the ice sheets alone explain a substantial portion of the observed climate variability since eighteen thousand years ago. For the late Holocene, since about six thousand years ago, we might expect that insolation changes alone would drive a slow and predictable climatic response that constitutes the long-period background against which we observe interannual-to-centennial scale climate anomalies.

Thompson (1995) has recently argued that orbital variations produce significant climate effects discernible over much shorter timescales (e.g., decades to centuries) than those typically associated with Milankovitch forcing. Thompson suggests that complex interactions between the tropical year (the time between equinoxes: 365.2422 days) and the anomalistic year (perihelion to perihelion: 365.2596 days) explain much of the observed climate variability at some locations over the past three hundred years. In central England, where the instrumental temperature record extends back to A.D. 1659, the annual cycle of temperature fluctuation is out of step with the tropical seasons by exactly the number of days that perihelion has changed over this 335-year record (eleven days). This work, which is still being evaluated by the climatology community, suggests that: (1) interdecadal-to-centennial climate variability at many locations may be tied to the precessional cycle; (2) removal of precessional background trends accentuates the magnitude of

residual global warming of the past fifty to sixty years; and (3) atmospheric carbon dioxide is the likely culprit for recent anomalous warming whereas solar variability has at most a small effect.

Atmospheric Trace Gas Variability

Trace gases such as carbon dioxide and methane are efficient absorbers of outgoing longwave radiation. Circulation models show that the 0.6°C global rise in temperature over the past hundred years is consistent with observed increases in atmospheric trace gas concentrations (Rind and Overpeck 1993; Hansen and Lacis 1990). Models also predict a global temperature rise of between 2 and 5°C with a doubling of the atmospheric carbon dioxide (IPCC 1990). Such a large, rapid change is postulated based on modern human activities. Natural variations in atmospheric loading of trace gases also occur, however, as carbon is exchanged among various marine and terrestrial reservoirs. Atmospheric carbon dioxide levels were 30 to 40 percent lower during the last glacial stage, when global temperatures were 4 to 6°C cooler. Analysis of air inclusions in ice cores suggests that natural atmospheric p–carbon dioxide variability is much smaller during the Holocene (5 percent, more or less). Nevertheless, natural p–carbon dioxide variability may still introduce a small aperiodic temperature signal into the Holocene climate system.

Abrupt Change Versus Periodic Climate Change

Considering the forcing mechanisms and large-scale climate systems discussed above, it is likely that most Holocene climate variability is periodic or quasi-periodic in nature. There is abundant evidence from instrumental and historical data sets for regular fluctuations in temperature and rainfall with periods ranging from biennial to centennial. Longer period fluctuations may exist but are not well documented. Superimposed on this background of rhythmically varying climate are short-term events or surprises. Major volcanic events would fall in this category, producing large regional to global anomalies that persist for two to four years with coincidental adjacent events producing anomalies lasting a decade or two. Atmospheric mechanisms can produce steplike changes in climate. A recent example of global extent is worth considering as a possible well-studied analog for similar events in the past.

Persistent climate anomalies since 1977 have been recognized throughout the globe, although the largest are observed in the Americas (fig. 2.12). These anomalies are linked to an abrupt shift in ENSO and the Pacific North America Pattern around 1976, and they persist to the present day (IPCC 1990, 1995). During the past twenty years, the tropical Pacific has been warmer than normal while the north Pacific has been cool. The number of El Niños exceeds the number of ENSO cool events. The PNA index has been positive

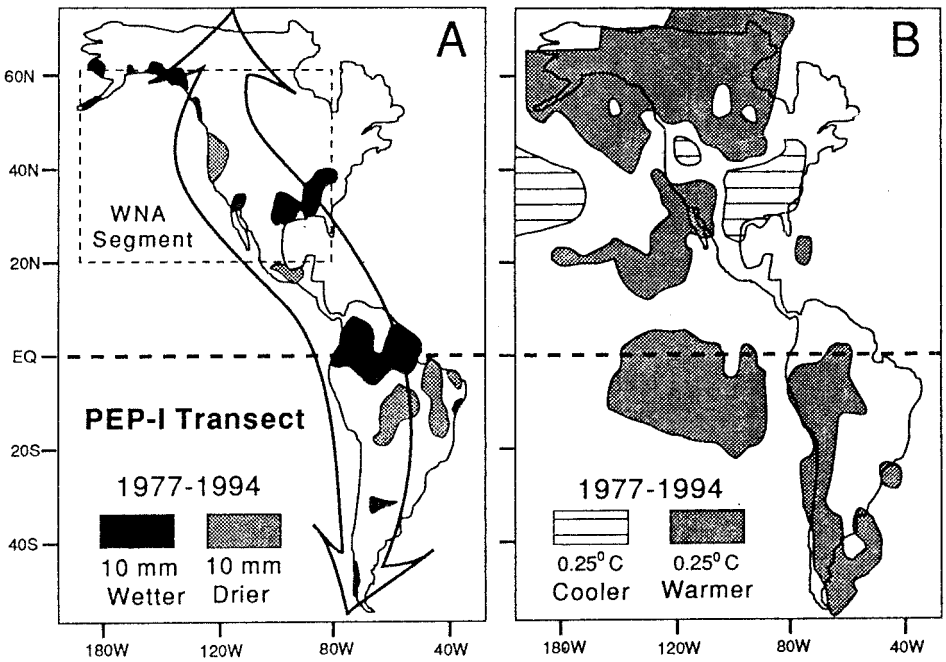


Figure 2.12.
The Western Hemisphere showing a proposed paleoclimate study transect (PEP-1) as well as climate anomalies during 1977–1994 relative to the pre-1977 period. (a) Precipitation anomalies from December to February. (b) Persistent anomalies in sea surface temperature and air temperature over land, December to February.
From Anderson and Dunbar 1995; data courtesy of H. F. Diaz.

with the corresponding climate effects in North America discussed earlier. South America has experienced anomalously wet conditions in Ecuador/northern Peru and southeastern Brazil, whereas much of the Amazon Basin and northeastern Brazil has been dry. The exact cause of this abrupt shift in the mid-1970s is not known. We do know, however, that the climatic anomalies shown in figure 2.12 are already affecting people and ecosystems. Catastrophic flooding in the southern and central United States can be linked to the post-1976 anomalies. It appears likely that drought conditions in the central Amazon since 1976 have contributed to an acceleration of deforestation and biomass burning (Anderson and Dunbar 1995). Forest diebacks in the Pacific Northwest also appear related to recent persistent drought. How often do such abrupt shifts occur during the Holocene? The network of high-resolution paleoclimate sites on land and in the ocean is too sparse to answer this question with certainty. It is unlikely, however, that the current shift is unique.

Case Studies: Late Holocene Climate Variability

Several recent studies provide new insights into the nature of late Holocene climate variability. Thompson et al. (1995) analyzed ice core records from Huascarán, Peru, a site recording Holocene and late glacial conditions in the

high-elevation tropics. Based on isotopic, chemical, and floral (pollen) tracers, they found that Holocene temperatures were warmest between 6500 and 5200 years B.P., a result consistent with many previous studies of Holocene climate. The new Peru cores show gradual cooling through the latter half of the Holocene to a temperature minimum between two hundred and five hundred years ago (fig. 2.13). Superimposed on this overall cooling trend are several oscillations of variable length and with amplitudes approaching that of the most recent Little Ice Age period. Six major Holocene dust events occur that may correspond to periods of aridification in the sub-Andean region. Thompson et al.'s record argues for significant multicentury to millennial temperature variability in the tropics. They have not yet examined higher-frequency signals in their ice cores, but the Huascarán site lies within the eastern Pacific center of action for El Niño thermal and precipitation anomalies and should provide a high-quality record of ENSO through the Holocene.

Figure 2.14 shows a compilation of ice core records spanning the last eight hundred years (Thompson et al. 1993). The presence of $\delta^{18}O$ in ice cores is generally interpreted in terms of temperature, with lower values indicating cooler temperatures. These cores, from plateaus in China, Peru, Greenland, and Antarctica, all show significant multidecadal variability, yet there is relatively little coherence between the individual records. In particular, the disparity between these records does not support globally synchronous

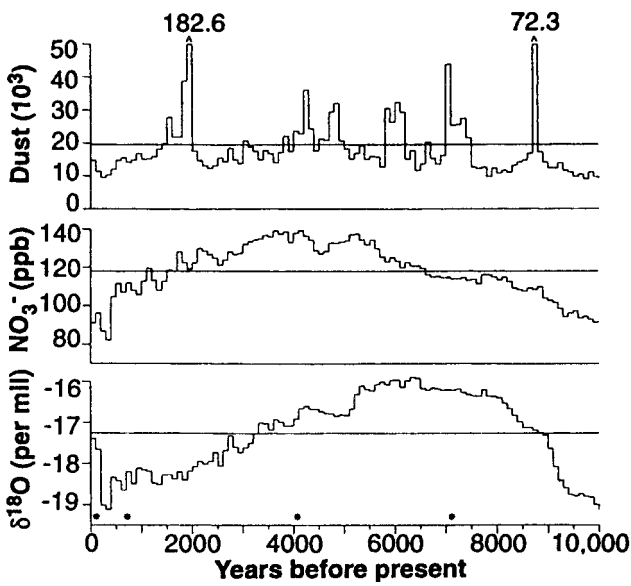


Figure 2. 13.
Hundred-year averages of $\delta^{18}O$, nitrate, and dust from Thompson et al.'s (1995) Holocene section of the Huascarán ice cores. Maximum Holocene warmth is evident from 8400 to 5200 years B.P., after which temperatures (from $\delta^{18}O$) cooled through the Little Ice Age.

From Thompson et al. 1995.

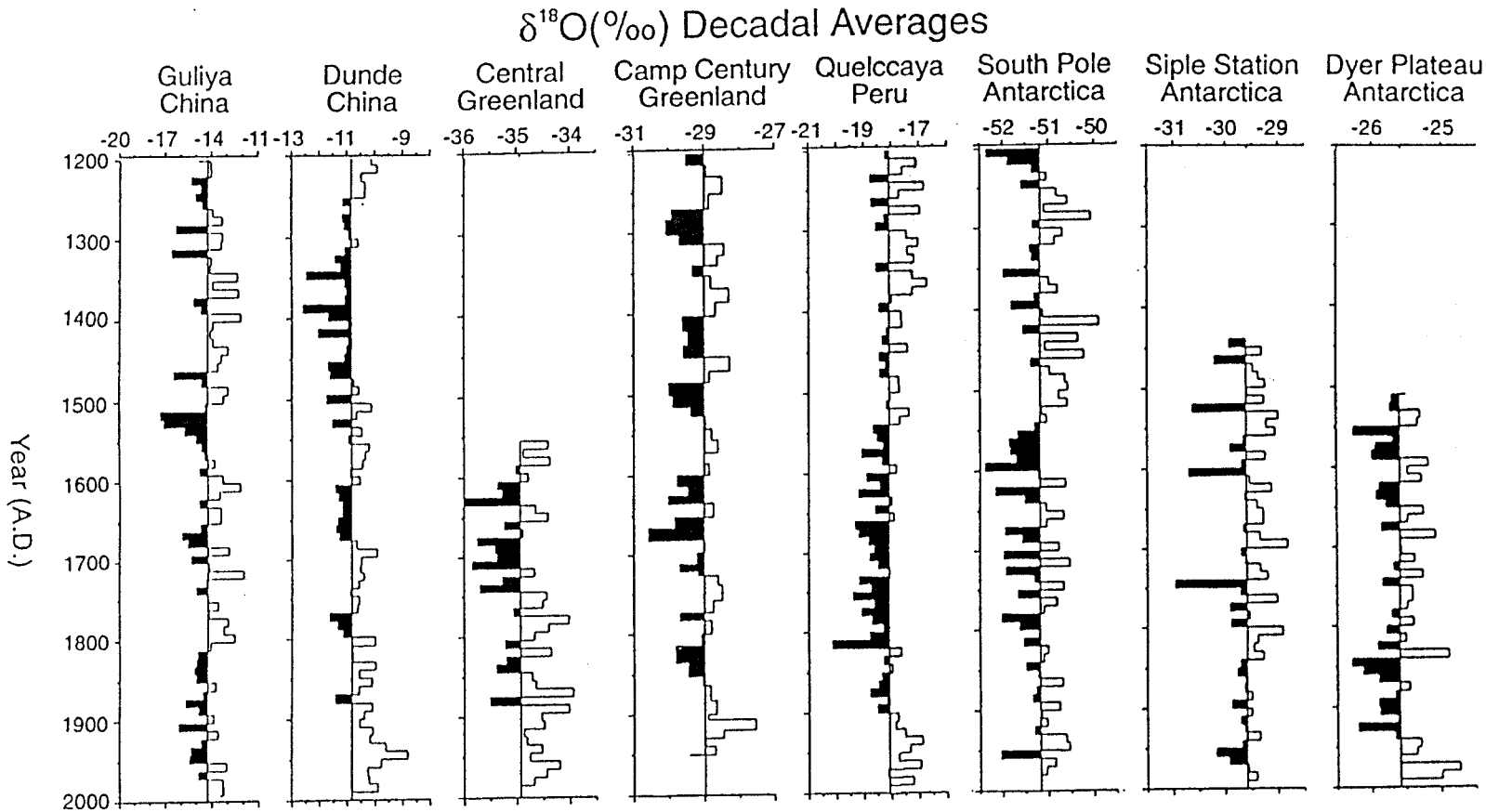


Figure 2.14.
Decadal averages of the $\delta^{18}O$ records from ice cores in several widespread locations. The shaded areas represent isotopically negative (cooler) periods relative to the individual isotopic means.
From Thompson et al. 1993.

warming during the thirteenth century (Medieval Warm Period) or cooling during the Little Ice Age. The lower latitude sites show warming trends since the late 1800s consistent with instrumental observations from lower elevations. Twentieth-century warming is not as apparent in the polar ice cores.

Hodell, Curtis, and Brenner (1995) examined the possible role of moisture balance on the Yucatan Peninsula in the decline of Mayan civilization. Their climate tracers include sediment-borne chemical and isotopic indicators of the filling and desiccation of Lake Chichancanab, Mexico (fig. 2.15). They found evidence for wet conditions between about 7100 and 3000 years B.P., very similar to observations from Lake Miragoine, Haiti (Hodell et al. 1991). Hodell and his colleagues suggest that an intensified annual cycle linked to changing precession of the earth's orbit provided an enhanced supply of moisture to this region. After 3000 years B.P., a long-term drying trend culminated in the most arid interval of the last eight thousand years, between A.D. 800 and 1000, a period corresponding with the collapse of the Classic Maya civilization. Inspection of the lake record shows several wet/dry oscillations in the five hundred years preceding the decline and implies that the Maya had several dry runs for developing strategies to deal with multidecadal drought in advance of the terminal event. This may indicate that such strategies were never developed, that they were not sufficient, or that climate change was but one of several factors contributing to the Maya collapse. In fact, the Chichancanab record provides evidence for strong century-scale perturbations in moisture balance throughout most of the nine-thousand-year record. It may be that such long oscillations could not be easily documented or perceived by the Mayans, a necessary prelude to the development of coping strategies.

Cook et al. (1991, 1992), Graumlich (1993), and Briffa, Jones, and Bartholin (1992), and Briffa et al. (1995) provide some of the longest tree ring records yet available (fig. 2.16). Tree rings provide annual resolution climate signals and can be used to assess higher-frequency climate variability in the latest Holocene. An eleven-hundred-year tree ring chronology from a Tasmanian Huon Pine (Cook et al. 1991, 1992) shows multidecadal to century-scale temperature oscillations on the order of 1 to 2°C. The most anomalous warming of the entire record is the post-1965 interval, a finding generally supportive of greenhouse gas forcing. Other warm intervals in this rare Southern Hemisphere record include A.D. 940 to 1000, 1100 to 1190, and 1475 to 1490. Little Ice Age cooling is not apparent. Intriguingly, extreme cooling in the early 1900s followed by rapid warming suggests a reorganization of the Southern Hemisphere ocean-atmosphere system in the early- to mid-1900s (Cook et al. 1991).

Graumlich (1993) used tree ring indices of Foxtail Pine and Western Juniper to reconstruct summer temperatures and winter precipitation in the Sierra Nevada. Estimated temperature anomalies are on the order of 1 to 2°C; variance is concentrated largely at periods of one hundred years or more. Anomalously warm temperatures prevailed between A.D. 1100 and 1375;

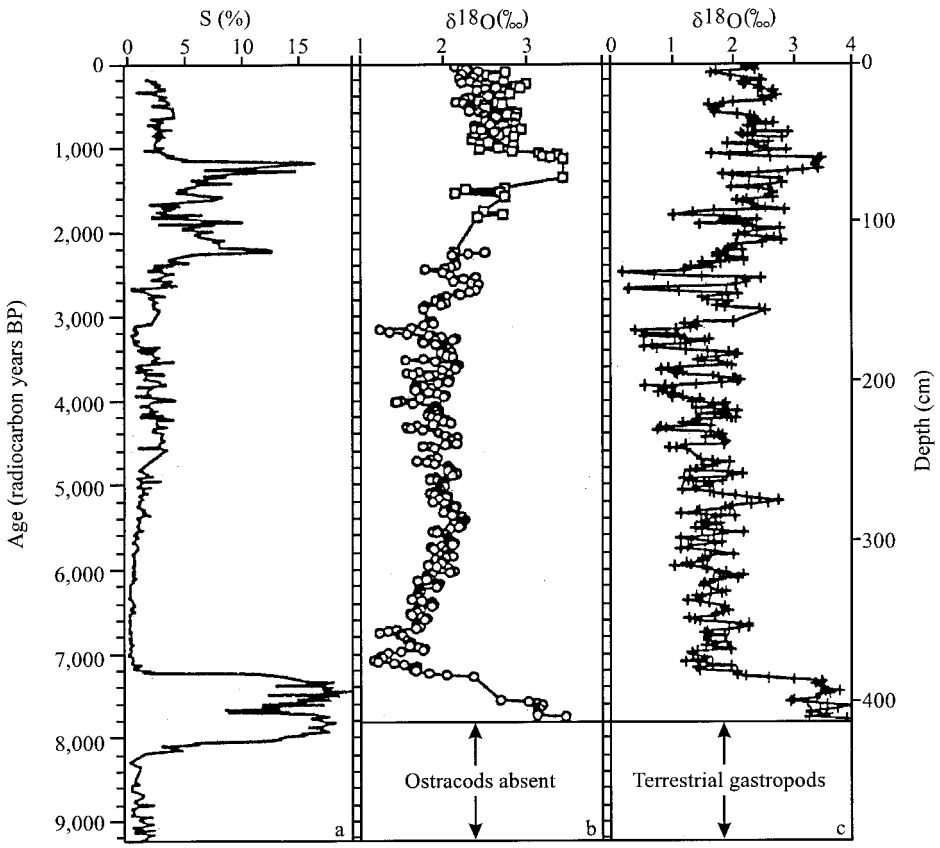


Figure 2.15.
Panel on this page: sulfur content (a) and $\delta^{18}O$ values for (b) ostracods and (c) gastropods in sediment cores collected from Lake Chichacanab, Mexico. Periods of dry climate are indicated by sulfur peaks and more positive $\delta^{18}O$ values. Panel on facing page: The last three thousand years of the sequence along with major subdivisions of Maya cultural evolution.
From Hodell, Curtis, and Brenner 1995.

cooling occurred between 1450 and 1850. At this site, the twentieth century is unremarkable in terms of warmth but does exhibit unusual precipitation variability. Throughout the record, precipitation is characterized by oscillations with periods between one and two decades. The twentieth century shows a rapid increase in precipitation to levels that have occurred briefly only three times previously.

Briffa et al. (1995) compare thousand-year summer temperature reconstructions from tree rings in Scandinavia and the northern Urals in Russia. Both records show multidecadal temperature anomalies of about 1 to 2°C. The Scandinavian reconstruction shows variance at periods of about thirty and sixty-five years, consistent with forcing by changes in the North Atlantic Ocean. The Urals reconstruction shows extended warm and cool intervals of

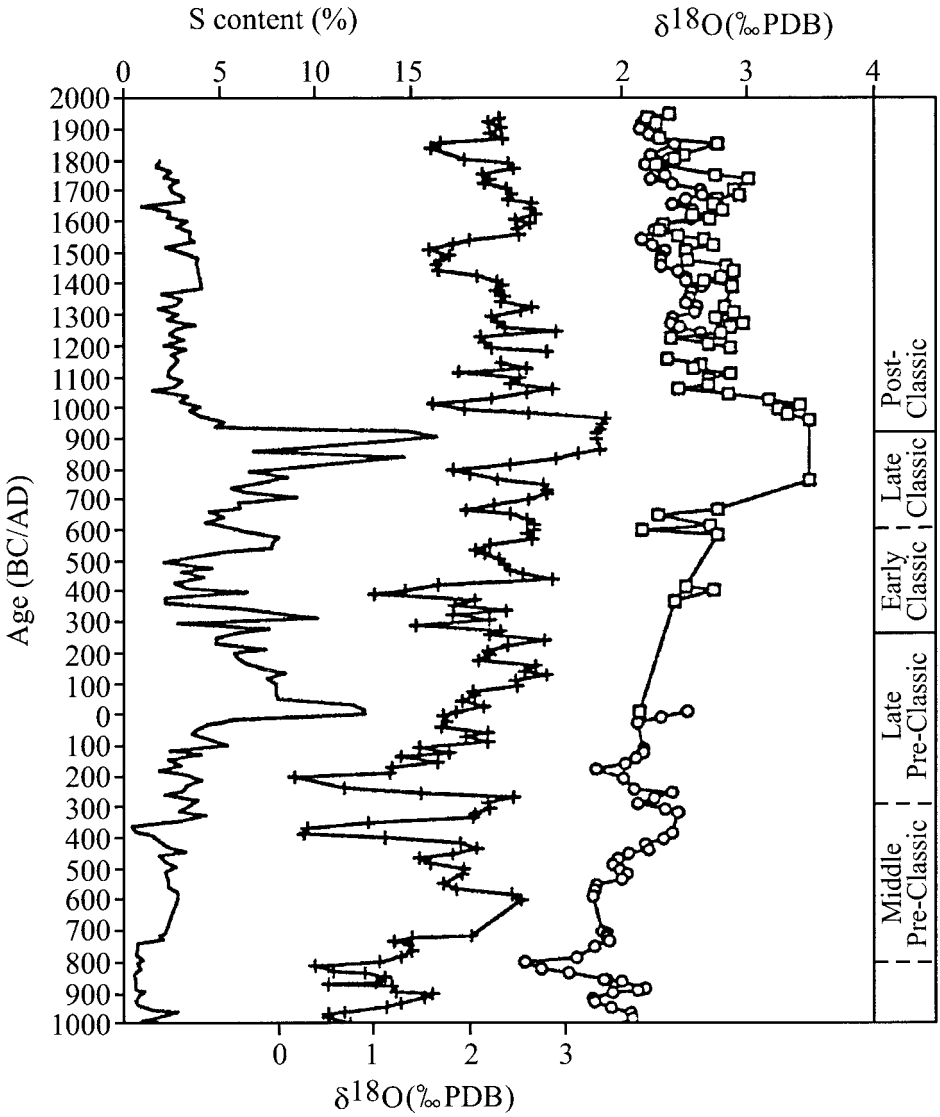
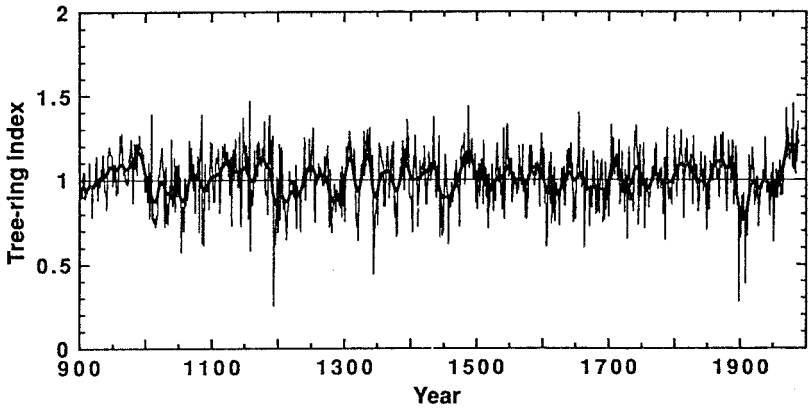


Figure 2.15. (*continued*)

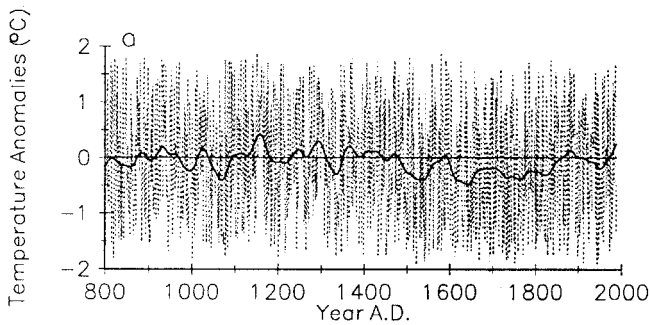
one to two centuries in length, as well as significant decade-scale variability. Cool conditions between A.D. 1100 and 1350 in Scandinavia coincide with warm conditions in the Urals, again challenging the notion of a Medieval Warm Period. Warming in the twentieth-century Urals record is unprecedented in the preceding nine centuries; anomalous twentieth-century warmth is absent in the Scandinavian record.

What conclusions can we draw from consideration of the Holocene records derived from ice cores, lake sediments, corals, and tree rings that are discussed in this paper? The two studies that extend through the Holocene provide support for significantly different mid-Holocene climates linked to

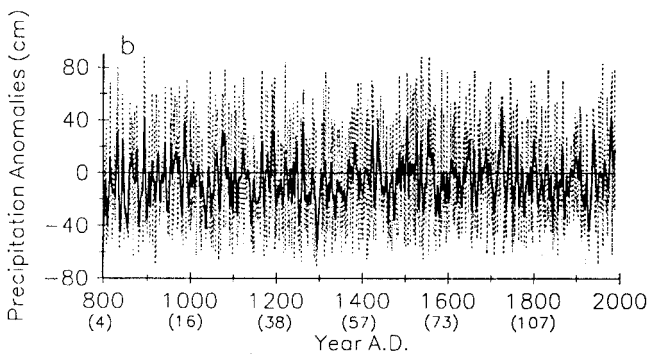
a.


Tree-ring Index
2
1.5
1
0.5
0
900
1100
1300
1500
1700
1900
Year

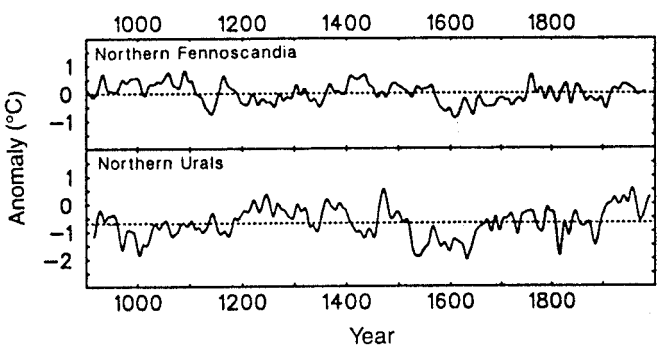
b.


a
Temperature Anomalies (°C)
2
1
0
−1
−2
800
1000
1200
1400
1600
1800
2000
Year A.D.

c.


b
Precipitation Anomalies (cm)
80
40
0
−40
−80
800
(4)
1000
(16)
1200
(38)
1400
(57)
1600
(73)
1800
(107)
2000
Year A.D.

d.


1000
1200
1400
1600
1800
Northern Fennoscandia
Northern Urals
Anomaly (°C)
1
0
−1
−2
Year

precessional variations in solar insolation. Rainfall patterns were different in the tropics and subtropics, and most areas were warmer. It is not yet clear that mid-Holocene warmth was universal. Background variability during the later half of the Holocene consists of steady gradual change consistent with precessional forcing.

All records with annual-to-decadal resolution show significant decade-to-century scale variability. Temperature variability over this timescale is most often in the range of 1 to 2°C. Only about half these records reveal the late twentieth century as anomalously warm. The few annual records that document variability in rainfall show variance at generally higher frequencies than characterizes changes in temperature. The style of climate variability is consistent with a variety of forcing mechanisms that are likely operating simultaneously. Most of the records I have selected as examples have high-quality chronologies and calibrations to climate. Interestingly, there is relatively little coherence between century-scale climate anomalies over distances greater than around one thousand kilometers (around six hundred miles). In particular, the data do not support global or even hemispheric century-scale warming or cooling events during the later Holocene. It appears that the climatic response to at least some of the operative forcing mechanisms is spatially heterogeneous. At first, this result may seem to complicate hopelessly the prognosis for understanding Holocene climate variability. The silver lining is that as climate models have become better at simulating past variability, they tend to show different patterns of climate response to forcing by different variables. As the models continue to improve and we acquire better spatial coverage of high-quality paleoclimate reconstructions, we have a very real possibility of sorting out the relative influences of the various forcing mechanisms.

Figure 2.16 (*facing page*)
Long tree ring records. (a) The Lake Johnson (Tasmania) Huon Pine tree ring chronology. The smoothed curve superimposed on the annual indices emphasizes fluctuations of twenty or more years in duration. The index change from low values in the early 1900s to high values at the end of the record corresponds with a measured temperature change of about 2°C. (b) Tree ring reconstructed summer temperatures and (c) winter precipitation anomalies expressed as departures from the mean of the observational period (1928–1988). The smoothed lines emphasize variability at the periods found to be most significant from spectral analyses (more than a hundred years for temperature and more than fourteen-and-a-half years for precipitation). (d) Summer temperatures reconstructed from tree ring series in Fennoscandia (upper) and the northern Urals (lower) smoothed with a twenty-five-year low-pass filter. The vertical axis corresponds to anomalies relative to the 1951–1970 interval. Dotted lines show the means for the entire record.

(a) From Cook et al. 1991; (b) and (c) from Graumlich 1993; (d) from Briffa et al. 1995.

What inferences can be made about the possible impacts of climate change on developing cultures during the Holocene? Given the relatively small temperature anomalies that occurred as a result of interannual to multidecadal periodic or aperiodic forcing during the Holocene, it is likely that region-specific changes in the hydrologic cycle produced the greatest societal and economic challenges. Prior to the advent of some form of record keeping, it seems unlikely that annual strategies for coping with drought or flood events could be developed even in areas with highly regular and sizable climate oscillations at subdecadal periods. When record keeping became routine, those cultures with some level of awareness of at least the natural variability in rainfall and perhaps even an understanding of the characteristic timescales of drought/flood cycles would be at some advantage in managing their agricultural and commercial resources. Few examples of such awareness and coping strategies exist (even for the present day); however, some possible target regions for studying societal responses include western South America (large ENSO-induced precipitation variability), the Ethiopian highlands and Nile Valley (ENSO- and monsoon-induced flood variability), Western Europe (North Atlantic Oscillation influence on the growing season), West Africa (Atlantic Dipole and Southern Ocean Wave impacts on precipitation), and Indonesia/Australia (ENSO-related drought events). All these areas supported ancient civilizations and show large, dynamic climate responses with interannual-to-decadal periodicities.

Summary

1. Analysis of climate change based on the instrumental record does not fully convey the scales and type of variability characteristic of much of the Holocene. Nevertheless, modern climate systems provide a useful starting point for examining past variability. In particular, global or hemispheric climate systems such as ENSO, the monsoons, the Pacific/North American Pattern, and the North Atlantic Oscillation likely existed throughout the Holocene, imparting characteristic periodicities and system responses.

2. ENSO contributes to worldwide variability in rainfall and temperature through a series of far-reaching teleconnections. The best-known ENSO periodicities correspond to the return times of El Niño and range from two to ten years. Multidecadal variability is also common, however, with periods ranging from twenty to a hundred years. In areas with a strong ENSO response or teleconnection, this system may well be the predominant paleoclimate pacemaker during the Holocene. This may be a fruitful system for analysis of cultural accommodation because of the timescales of the climate perturbation and its quasi-periodic behavior.

3. Evidence is emerging from annual-resolution marine records that late Holocene climate may be characterized by successive century-scale intervals

with characteristic variance spectra separated by decadal-scale periods of relatively rapid change in the dominant periods of variance. In other words, the return periods of certain types of climate events, such as drought, may be time-trangressive on a century timescale. This type of variability may be more difficult for societies to deal with than long-period steady change. Earlier mode shifts appear to have occurred in the mid-1700s and mid-1800s. The most recent example may well be the 1976–1977 abrupt change in many climate indicators worldwide.

4. In many parts of the tropics, changes in precipitation patterns may be the predominant consequence of climate change. High-resolution studies of three-hundred-year-old corals provide evidence for long-term changes as well as decadal-scale variability in the Central American Monsoon. Sediment data from Lake Chichancanab suggest that very large changes in Central American rainfall have occurred over the past eight thousand years, with the strongest drought during this interval at about A.D. 800 to 1000. A tree ring record from California suggests that high rainfall during the late twentieth century is anomalous relative to most of the preceding thousand years. Reconstructions of rainfall in the tropics and subtropics at annual (or better) resolution are relatively rare but are needed if we are to appreciate Holocene climate variability where most humans have lived.

5. The best example of near-global synchroneity in Holocene climate is the mid-Holocene climatic optimum, a time of widespread (but perhaps not ubiquitous) warm/wet conditions linked to precessional changes in solar insolation. Other events long held to be universal, such as the Little Ice Age and Medieval Warm Period, are in fact restricted to specific regions in terms of century-scale expression. There are some examples of near-global cooling with a persistence of one or two decades (such as the early 1600s and early 1800s). These may have their origin in nonperiodic forcing mechanisms such as volcanic aerosol loading. The latest Holocene climate variability is probably best characterized by region-specific, decadal-to-multidecadal precipitation and thermal (0.5 to 1.5°C) anomalies. Many of these oscillations are periodic or quasi-periodic and linked to large-scale atmospheric systems.

6. The current generation of climate models produces results consistent with a number of different forcing/causal mechanisms for climate change, and we are by no means clear as to the relative effects of atmospheric variability versus solar, volcanic, or trace gas forcing. When models are run with specific forcing mechanisms, however, they often produce predictions of a characteristic regional climate response that may in fact be subject to verification using paleoclimate data.

7. A number of recent studies have conclusively demonstrated a larger-than-expected contrast between glacial age and modern climates (particularly at low latitudes). This removes old philosophical barriers to acceptance of significant Holocene climate variability and has helped fuel a rejuvenation in Holocene climate studies. Fortunately, this increased interest in the

Holocene has also attracted a substantial increase in recent research funding. The research focus during the first decade of the twenty-first century will be to develop highly accurate, annual-resolution (or better) late Holocene paleoclimate records from areas for which few data exist. This includes the study of marine systems, using corals, sclerosponges, mollusks, and laminated sediments, as well as of terrestrial tropical and subtropical systems, using tree rings and lake sediments. There will be increased analysis of the forcing of terrestrial climates by large-scale marine systems. The Central Pacific in particular seems to lead and force worldwide climate variability at subdecadal periods. The North Atlantic deep water production system is a likely candidate for explaining multidecadal variability in the adjacent and downstream areas of Greenland and northern Europe. Detailed hindcast tests of numerical models of the coupled ocean-atmosphere system are already under way. This will continue and drive needs for data collection in specific regions sensitive to different kinds of climatic forcing. Spin-offs for studies of the effect of climate change on humans include: (1) study of the vast amount of data on late Holocene climate variability in the tropics and subtropics (where most humans have always lived) that will become available over the next few years, and (2) numerical models of the modern climate system, both of which can already provide insights as to where quasi-periodic climate changes may have been large, as well as areas that were climatic refugia. Identifying such locations permits the informed selection of sites for the analysis of human responses to periodic and, occasionally, abrupt changes in climate.

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Chapter 3

Complexity Theory and Sociocultural Change in the American Southwest

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Scientific perspectives on the relationship of human societies to the natural environment have ranged from doctrinaire environmental determinism to the contention that environment has minimal impact on human societies. Most scientists, however, occupy positions between these two extremes. While few would deny that behavioral adaptation to natural environmental variability is an important factor in sociocultural change and evolution, equally few would maintain that environment alone determines the resulting adaptive configurations. The degree to which environment actually influences culture is a situational issue that must be ascertained empirically. Specific instances illuminate the general processes that drive sociocultural adaptation to environmental stability, variation, and change.

Human response to environmental fluctuations is conditioned by many factors, including interactions among key environmental, demographic, and cultural variables, each of which affects and is affected by the others in particular circumstances. A major cultural component of human adaptive behavior is the means by which societies accumulate, store, and retrieve information about the environment and viable responses to environmental variation. While the maintenance and use of knowledge is a cultural process, the information about adaptive behavioral response to environmental factors is a function of past environmental variability mediated by experience and ideology. Among the factors that affect this process are the nature of environmental variability and the cultural mechanisms by which knowledge is acquired, transmitted, processed, stored, accessed, and activated (see Gunn and Hassan in this volume). Because the natural and cultural processes involved in behavioral adaptation are structured by long-term interactions among environment, population, and culture, diachronic studies of adequate time depth are necessary to elucidate this matter. Archaeology is thus an appropriate avenue for examining these important questions.

The North American Southwest is especially suited for such studies for several reasons. First, it possesses a comprehensive archaeological record of

past population and behavioral variability across space and through time. Second, rich historical and ethnographic data on Native American cultures that evolved from prehistoric predecessors illuminate the archaeological record and elucidate prevailing mechanisms for managing information. Finally, the Southwest is blessed with detailed paleoenvironmental reconstructions of numerous variables on a broad range of temporal and spatial scales. This abundance of data illuminates interactions between environment and human behavior over the last several millennia and provides an unparalleled opportunity to investigate the ways in which cultures transform knowledge and ideology into adaptive responses to environmental variability.

Despite the quality of the database, four additional conditions must be met before we can develop the implications of southwestern prehistory for understanding the role of information management in human adaptation to environmental conditions. First, a conceptual foundation must be established for (1) integrating information management with the behavioral aspects of sociocultural adaptation and evolution and (2) connecting information management and adaptive behavior to the past behavioral events and relationships that are discernible in the archaeological record. Complexity theory serves this function by incorporating cultural systems into a more general class of phenomena—complex adaptive systems—and specifying the important features and processes such phenomena have in common. Second, environmental variability must be partitioned and measured to emphasize connections with and relevance to human societies, cultural systems, and behavior. Third, the cultural component of the adaptive process must be characterized in ways that enhance archaeological examination of adaptation in general and its operation in the study region. Behaviors that are related to adaptation and can be perceived in the archaeological record must be identified, and their general and local archaeological manifestations defined. Finally, the ways in which organized behaviors relate to and interact with environmental variability and change must be specified.

Information Management in Sociocultural Adaptation

The concept of social memory has great explanatory potential in the effort to understand cultural adaptation, change, and evolution. Social memory, which combines the long- and short-term aspects of codified communal understandings of landscape and biocultural dynamics, is a major component of societies' self-referenced understandings of their internal and external universes. As repositories of information about the world, these aspects of culture are vital to human behavioral adaptation to changing physical and social conditions. Scientific understanding of social memory is enhanced by examining it within the broader context of a general class of phenomena called complex adaptive systems. Complex adaptive systems (Gell-Mann

1994, 1995; Holland 1995; Kauffman 1993) are capable of changing in response to external or internal stimuli and thereby adapting to altered circumstances and, in the process, evolving into new systems and/or generating other complex systems.

Obviously, a society's ability to accumulate, store, retrieve, and use information about crucial aspects of its natural environment is vital to its survival (Gunn and Hassan in this volume). Social memory performs these necessary adaptive functions. Social memory cannot, however, record, store, and process *all* instances of environmental variability, interaction, or impact throughout the history of a society or the experience of its members; therefore these memories, like other aspects of culture, are compressed into *schemata*, features that are integral components of all complex adaptive systems (Gell-Mann 1992, 1994:17, 75, 1995; Holland 1995; Kauffman 1993; Wills et al. 1994). Schemata are evident in a broad spectrum of phenomena ranging from the behavior of individual humans trying to extract order from a series of events (Gell-Mann 1994:17–18) to the operation of biological evolution (Holland 1995).

A schema organizes and codifies repetitive or nonrandom elements in a complex adaptive system's experience into a model of reality that is highly condensed relative to the breadth of information and individual experiences that went into it. Because random experiences cannot be compressed, they are not included in schemata. Schemata take a variety of forms across the spectrum of complex adaptive systems (Gell-Mann 1992, 1994, 1995; Holland 1995). In biological systems, they are embedded in DNA; in science, they are theories that compress the natural variability of the observed world into short statements; in human social systems, they are cultures and subsets of cultures such as languages, ideologies, kinship systems, social memory, and other organized elements that guide human behavior.

Cultural schemata are hierarchically organized. Subordinate schemata are subsumed by higher-level, more inclusive sets. For example, at the lowest level in the hierarchy might be individual schemata developed as a result of each person's efforts to make sense of his or her own unique life experiences (Gell-Mann 1994:17–18). Each individual schema is shaped by more general schemata that encode the many layers of the culture in which that person participates. Above the level of the individual are schemata that govern specific ranges of patterned behavior such as the manufacture of tools, the construction of buildings, the acquisition of food and other resources, child care, and numerous other operations. In most societies, few if any individuals possess knowledge of all these schemata. No single person, for example, is likely to know the accepted ways of producing ceramic vessels, baskets, arrow points, bows, arrows, metates, manos, and other items. Rather, the concepts and training necessary to execute these tasks are differentially allocated to members of the society based on criteria such as age, sex, kinship, experience, and ability. Such specialization, a characteristic of all complex adaptive systems (Wills et al. 1994:299–302), allows the existence in any single society of a wide array of specialized schemata that are consolidated in

higher-level schemata. Higher-level schemata in which most members of a society participate include kinship and religious systems. The disparate knowledge, relationships, and behaviors inherent in these systems are integrated into a conceptually coherent package by still more inclusive schemata embedded in the belief system, ideology, worldview, language, and other subsystems. Finally, the many schemata are subsumed under the overarching schema of a culture, an ill-defined, difficult to observe, but nonetheless powerful construct that fuses the many subordinate elements into a single, though not monolithic, entity and provides individual humans with senses of identity, commonality as members of a delimited sociocultural entity, and distinction from (and often superiority to) nonmembers of their culture.

By organizing past experience into a coherent model of reality, a culture-level schema places events and relationships into recognizable (repetitive) categories and allows a system to respond in patterned ways to situations that arise. So long as the schema's expectations about possible conditions are reasonably accurate, it contributes to the perpetuation of the system. Repeated faulty performance reduces a system's fitness and the probability of its survival in competition with other systems. The incorporation into the schema of new information inherent in such situations allows the system to adapt to changed circumstances and thereby enhance its fitness and survivability. As a quintessential schema, social memory is a vital element in the adaptation of a culture to changing circumstances, the survival of the system, the development of individual cultures, and the evolution of culture in general.

Within the context of adaptation to long-term environmental change, environmentally relevant schemata are cultural constructs that vary between and within individual cultures. A particular society's schemata are outcomes of (1) the structure and operation of the culture, which itself is an evolutionary product, (2) the contingent history of the human bearers of the culture (Gould 1989; McGuire 1994), and (3) the range of environmental conditions and variations experienced by the group during its history. These elements (and, no doubt, others) interact to give each culture unique attributes that differentiate it from all others, even those that occupy the same habitat. In the Southwest, for example, Navajos and Hopis inhabit the same area but differ profoundly in their cultural perceptions of this environment. The major ideological and behavioral differences between these two groups (Hall 1994) result from the application of different schemata to the same environment, schemata that are conditioned by different evolutionary trajectories and contingent histories. Thus distinct, internally consistent schemata allow cultures based on residentially constrained mobile pastoralism (Graham and Roberts 1986) and sedentary agriculture (Bradfield 1971; Levy 1992) to coexist in the same locale, essentially by creating and exploiting separate conceptual and economic niches. Different origin myths, traditional histories, environmental perceptions, and other cultural constructs express the different schemata that organize reality in the Navajo and Hopi complex adaptive systems.

Within-culture variation in schemata depends on internal variations in

structure, contingency, and environmental experience. Differences between Hopi settlement clusters (mesas) and even between the villages of a single cluster are conditioned by the different histories experienced by the precursors of these social units. Contingent differences encoded in each group's social memory are expressed in the unique traditions and ceremonial complexes possessed by each village. Similarly, the social memory of the eastern Navajos is strongly influenced by the Long Walk of the 1860s (Bailey 1964), when thousands of people perished during the forced march to Bosque Redondo, whereas that of western Navajos, whose ancestors escaped the Long Walk, is configured more by the Stock Reduction Program of the 1930s.

As outcomes of historical and evolutionary processes, environmentally relevant schemata have time depth. Social memory's multigeneration span means that additions to this domain usually can be identified in ethnographic or historical records. In fact, there is no effective limit on the time depth of information in the social memory, and McIntosh (this volume) identifies potential Pleistocene roots for elements of Mande traditional knowledge.

In the Southwest, archaeological evidence specifies different time depths for different aspects of Puebloan social memory. The presence of *sipapus* (floor holes representing the ancestors' emergence to the earth's surface) in Basketmaker III pithouses indicates that knowledge encoded in Puebloan origin myths goes back at least fifteen hundred years. In contrast, the organization of information represented by the Katsina cult probably is less than half that old (Adams 1991). The temporal attributes of Navajo traditional knowledge are more difficult to apprehend, but it seems likely that some ancestral Athapaskan elements, in addition to language, can be traced at least a millennium into the past. Other elements of Navajo social memory, particularly those relating to architecture, weaving, and animal husbandry, can be traced to Puebloan, Spanish, and even Anglo antecedents less than four hundred years old (Amsden 1934; Brugge 1968; Towner 1996).

Identifying cultures as complex adaptive systems and varieties of social memory as schemata establishes the necessary conceptual link between information management and archaeologically discernible behavior and has considerable theoretical potential for explaining sociocultural adaptation to environmental variability and change. Operationalizing these concepts for archaeological investigation, however, remains difficult because of their nonmaterial nature. Nevertheless, attempts can be made when environmental variability can be characterized in terms relevant to human behavior, the cultural component of human adaptation can be expressed in behavioral terms, and potential interactions between environmental and behavioral phenomena can be conceptualized.

Environmental Stability, Variability, and Change

The natural environment includes a myriad of elements (rocks, soils, ground and surface water, flora, fauna, climate, and others), many of which comprise

numerous components as exemplified by the division of climate into air pressure, precipitation, temperature, humidity, growing season, wind, drought, and other factors. Furthermore, each component varies over timescales of minutes to millennia and geographic scales of millimeters to continents. Any study of human response to environmental variability must therefore focus on components and temporal and spatial wavelengths thought to be relevant to the specific instance of human behavioral adaptation under investigation. In the preindustrial Southwest, for example, temporal variability ranging from seasons to millennia and spatial variability ranging from localities to the region as a whole probably had important adaptive consequences for the resident societies.

Within the context of an infinitely variable environment, the concepts of environmental stability, variability, and change take on specific connotations. *Stability* refers to a lack of change in the nature of and relationships among pertinent environmental factors over finite time and space dimensions that are defined by the parameters of the study. *Variability* refers to quantitative variations around relatively stable averages over time and to geographic variations within defined environmental types. Put somewhat differently, variability involves fluctuations within a so-called normal range considered to define a prevailing state of the factor in question. *Change* involves more or less permanent alterations in the natural factors and processes that regulate the temporal and spatial aspects of environmental variability, that is, transformations from one state to another. Temporal change creates qualitatively different environmental regimes characterized by new means and/or variances, while spatial change involves the transit from one environmental type to another. In order to survive, human societies must adjust their behavior to the range of variability in established temporal means and geographic patterns.

Environmental variables have attributes that can be classified into amplitude, temporal, and spatial components. *Amplitude* variability is captured by measuring, on appropriate absolute or relative scales, the magnitude of variation in a factor and by summarizing this variation with parameters such as means, medians, modes, ranges, variances, and extremes. *Temporal* variability is characterized in a variety of ways. Chronological properties are used to assign the natural processes that regulate environmental variability to high- or low-frequency domains. In addition, environmental variation exhibits both low and high temporal variability in which transitions between high and low values occur, respectively, slowly or rapidly. Other temporal attributes include trend (the direction of change over time), duration (the time spans over which conditions or trends persist), and recurrence interval (the frequency with which defined conditions, such as extreme high or low values, repeatedly occur). *Spatial* environmental variability can be homogeneous or heterogeneous and exhibit many patterns within these broad categories, including mosaic, gradational, coarse-grained, fine-grained, even, and mixtures of the foregoing (Plog et al. 1978).

These conditions are characterized by synchronic measures of magnitude, central tendency, variance, and extremes. Geographic variation ranges from high, when change occurs across relatively short distances, to low, when uniformity prevails over long distances.

Just as the various elements and attributes of environmental variability and change limit possible adaptive responses, scientific investigation of these responses is limited by our ability to apprehend the general patterns and nuances of environmental variation through time and across space. Because useful instrumented environmental records extend fewer than a hundred years into the past, we must rely for long-term information on paleoenvironmental reconstruction techniques, each of which is sensitive to different elements and to different frequencies of temporal and spatial variation in these elements. Thus, while most environmental elements vary continuously along the time and space dimensions, reconstruction techniques are capable of revealing only limited segments of the total spectra. Research questions must therefore be framed in terms of environmental variability that actually can be perceived through paleoenvironmental reconstruction, a handicap that of course legislates imperfect understanding of systemic adaptive behavioral change and evolution.

Behavioral Response to Environmental Variability

Archaeology can observe nonmaterial aspects of culture, such as social memory and information management, only through the medium of the behavior that produces the archaeological record. For several reasons, nonbehavioral aspects of a culture are poorly represented in this record. First, because of the operation of the cultural and natural processes that create and alter the archaeological record (Schiffer 1976, 1987), evidence for the complete range of a group's activities is highly unlikely to survive to the present. The resulting incomplete behavioral record limits the inference of nonmaterial aspects of culture. Second, some nonmaterial components of culture (such as language) may have no behavioral correlates that leave archaeological traces, while others (such as religious prescriptions) may require the obliteration of the physical remains of related activities. Third, the links between the ideological domain and behavior are not always linear and readily inferable from the material record of that behavior. Fourth, archaeology's ability to extract information from material remains and their relationships, though improving, is not perfect. On the other hand, human interaction with the physical environment usually involves actual behavior that commonly is archaeologically visible. These factors compel archaeologists to focus on behavior as the locus of sociocultural adaptation, change, and evolution and to deal more inferentially with nonmaterial aspects of culture.

From an archaeological perspective, human behavioral adaptation to environmental stability, variation, and change involves the interaction of

environmental, demographic, and behavioral variables (Dean 1988b; Dean et al. 1985). These variable classes are linked by the fact that any particular habitat can support a finite number of humans who employ a particular subsistence system (Hassan 1981). Under ordinary circumstances, these variables interact constantly to maintain a fluid but acceptable balance among the factors. When systemic limits, as defined by the number of people supportable in the prevailing environment by the extant subsistence system, are approached or breached, stresses develop that require adaptive responses in order to maintain the population. Generally, stress situations develop when growing population intersects an environmental threshold or when environmental deterioration lowers the threshold below the population level (Dean 1996a:fig. 1). Resulting systemic changes in the relationships among the variables create new, qualitatively different adaptive configurations. While any of the components can respond to these situations, environmental factors usually behave as independent variables, while population and behavior usually act as dependent variables. This is not to say that demographic and behavioral variability does not affect the environment. Both can have intended or inadvertent environmental consequences that in turn may require further adaptive population or behavioral changes.

Demographic responses to stress situations usually involve population reductions that maintain the number of people below the systemic limit. Such reductions can be achieved intentionally, as through emigration or the regulation of births and deaths, or inadvertently, as through the effects on birth and death rates of malnutrition, disease, or starvation.

Behavioral reactions to systemic stress can take many forms. Perhaps the first to be invoked are technological responses that adjust the subsistence system to the new conditions. Such responses include the use of different tools, better-adapted crop plants, more efficient food processing and storage practices, previously underexploited localities or habitats, and previously underused techniques. Intensification, either through improved technology or more productive use of labor (Boserup 1965), is a common tactic in these situations. Social changes involve the organization and scheduling of the procurement, accumulation, storage, and redistribution of food and the allocation of access to critical resources such as farmland, water, wild plants, game, and raw materials. Finally, a common response to subsistence stress involves interaction with other groups through mechanisms such as trade, tribute, raiding, and even warfare. All these potential responses exist in a reservoir of behaviors that can be activated as circumstances warrant. Changing the mix of responses extracted from this reservoir allows societies to accommodate normal variability and adapt to the permanent changes in interrelationships among environment, population, and behavior that define qualitatively different adaptive configurations (Dean 1996a:fig. 2). Knowledge of the relevant behaviors, and their concomitant rationalizations and rules for activation, is maintained in the belief systems that make up the social memory of the group(s) involved. Southwestern prehistory provides a record of the actual adaptive behaviors selected by this process, thereby

generating insights into the nature of the information available to the populations of the region and the information management principles and systems that promoted the long-term survival of these populations.

Human Adaptation in the Southwest During the Last Two Thousand Years

During the last two millennia, the Southwest was occupied by relatively small populations of subsistence farmers who at certain times and places attained sufficient production levels to develop relatively complex societies. Except in the Sonoran Desert, where permanent rivers allowed irrigation agriculture, southwestern environments are marginal for the relatively simple subsistence farming technology available to the inhabitants of the region. Even in the deserts, the vagaries of climate and stream flow have seriously impacted subsistence (Nials et al. 1989). Therefore environmental variability and change had major effects on the populations of the entire region.

Especially after population levels approached or exceeded local or regional system limits, behavioral adjustment to environmental fluctuations was a virtually constant process. Changing emphases on various subsistence practices and organizational configurations allowed groups to adjust to all but the most extreme aspects of the normal ranges of amplitude, temporal, and spatial variability. Extreme departures from normal often required extreme responses, and when these departures became the norm to create qualitatively new adaptive circumstances, behavioral change was the only means by which the populations could be sustained. Paleoenvironmental and paleodemographic records identify instances when such adaptive changes were likely to have been necessary and illuminate environment-population-behavior interactions. These interactions in turn allow inferences about the role of information management in southwestern culture change.

Paleoenvironmental Reconstruction

The effort to understand the relationships between southwestern agricultural societies and their physical environments benefits from dividing the time continuum of environmental variability into three frequency bands based on the periodic structure of the physical processes that regulate this variability (Dean 1988b). The divisions are defined with reference to a standard—one human generation—that makes environmental variability relevant to human behavior. Processes with basic periods substantially longer than the time interval of interest—in this case, the last two thousand years—produce *stable* factors that have not changed appreciably over the specified period. *Low-frequency* processes have cycles greater than or equal to twenty-five years, the approximate length of one human generation. *High-frequency* processes are characterized by periods shorter than twenty-five years. These processes regulate a large number of potentially relevant environmental

factors, each of whose pertinence to any particular example of human adaptation is determined empirically.

Stable elements of the southwestern environment include the tripartite division of the region into desert, mountain, and plateau habitat zones; bedrock geology; gross topography; climate type; the elevational zonation of plant communities; and the general distribution of resources (arable land, surface water, springs, wild plant foods, clay for ceramics and adobe, and stone for masonry and chipped and ground stone tools). Apart from the eruptions of Sunset Crater, which altered the topography, geology, and agricultural potential of a small area near Flagstaff, exceptions to this generalization are minor and involve local episodic events such as rockfalls, landslides, and changes in stream courses. Because the stable components have not varied appreciably over the last two thousand years, their current states are accurate indicators of past conditions, and they need not be reconstructed.

Environmental fluctuations caused by low- and high-frequency natural processes vary over intervals much shorter than the study period; consequently, variability in the relevant factors must be reconstructed using available paleoenvironmental techniques. Low-frequency environmental elements that can be reconstructed include the rise and fall of alluvial groundwater levels, the deposition and erosion of floodplain sediments and slope deposits, large-scale climatic oscillations, variations in the moisture available to plants, fluctuations in plant community composition and boundaries, and changes in the composition and distribution of faunal populations. Paleoenvironmental techniques used to reconstruct low-frequency variability in these elements include alluvial geomorphology, palynology, dendroclimatology, packrat midden studies, archeobotany, and archeozoology. High-frequency paleoenvironmental reconstruction is limited to climatic factors (air pressure patterns, precipitation, temperature, drought, and growing season length) and other variables directly related to climate (stream flow, crop yields, and pollen production), which are reconstructed primarily by dendrochronology and high-resolution palynology.

Local environmental variability is revealed by numerous small-scale paleoenvironmental studies, of which I cite only a few examples here. Low-frequency fluvial, effective moisture, and climatic reconstructions are available for many places on the Colorado Plateau (Betancourt 1984, 1990; Betancourt, Martin, and Van Devender 1983; Betancourt and Van Devender 1981; Bryan 1940, 1941, 1954; Cooley 1962; Euler et al. 1979; Grissino-Mayer 1996; Hack 1942; Hall 1977, 1983; Hevly 1988; Karlstrom and Karlstrom 1986; Karlstrom 1988; Love 1980; Petersen 1988; Schoenwetter 1962; Schoenwetter and Eddy 1964) and for a few areas in the mountains and desert (Agenbroad 1982; Bryan 1940; Eddy and Cooley 1983; Sayles 1983; Sayles and Antevs 1941; Waters 1986, 1988a, 1991, 1992). High-frequency dendroclimatic reconstructions of relative climate (Dean and Robinson 1977, 1982; Fritts, Smith, and Stokes 1965), annual and seasonal precipitation (D'Arrigo and Jacoby 1991; Dean 1992; Grissino-Mayer 1996; Lebo 1991; Rose, Dean, and Robin-

son 1981; Rose, Robinson, and Dean 1982), drought severity (Rose 1994; Rose, Robinson, and Dean 1982; Van West 1994), stream flow (Graybill 1989; Smith and Stockton 1981; Stockton 1975), and crop production (Burns 1983; Garza 1978; Van West 1994; Van West and Altschul 1994) are available for many localities north of the Gila River. These reconstructions provide data for assessing the environment's role in cultural developments in the Rio Grande Valley (Ahlstrom, Van West, and Dean 1995; Wetterstrom 1986), the Four Corners area (Ahlstrom, Van West, and Dean 1995; Bryan 1954; Dean 1969, 1992; Dean, Lindsay, and Robinson 1978; Gumerman and Dean 1989; Lebo 1991; Petersen 1988; Plog and Hantman 1990; Schlanger 1988; Schoenwetter and Eddy 1964; Van West 1994), the Mogollon Highlands (Dean and Robinson 1982; Reid and Graybill 1984; Shaw 1993), southeastern Arizona (Eddy and Cooley 1983; Sayles 1983; Waters 1986), and the Tonto (Ciolek-Torrello and Welch 1994), Phoenix (Nials, Gregory, and Graybill 1989), and Tucson (Waters 1988a, 1988b) basins.

Fortunately, the wealth of local paleoenvironmental data can be synthesized into a few regional-scale reconstructions (Dean 1988a, 1996a; Dean et al. 1985; Dean and Funkhouser 1995; Dean and Robinson 1977; Euler et al. 1979; Hevly 1988; Schoenwetter 1970) that are more germane to this study. Especially relevant are reconstructions of alluvial hydrology, floodplain and slope deposition and erosion, effective moisture, precipitation, temperature, drought, stream flow, crop production, and measures that integrate combinations of these factors.

Figure 3.1 illustrates regional-scale low- and high-frequency variability in several environmental elements over the last two thousand years in the northern Southwest. The aggradation-degradation curve (a) depicts the accumulation (positive slopes) and erosion (negative slopes) of floodplain sediments along the drainages of the region. The hydrologic curve (b) illustrates the rise (positive slopes) and fall (negative slopes) of alluvial groundwater levels that accompany the deposition and erosion of alluvium. Both of these elements have been reconstructed through chronostratigraphic studies of floodplain alluvium with chronological control provided by radiocarbon, archaeological, and tree ring dating. Figure 3.1(c) shows fluctuations in the effective moisture available to plants as reconstructed by analysis of pollen samples from alluvial and archaeological contexts. Correspondences between the low-frequency Hay Hollow Valley effective moisture curve, the hydrologic curve, and a low-frequency dendroclimatic record from El Malpais National Monument in New Mexico (Grissino-Mayer 1996) testify to the basic unity of low-frequency environmental variability across the region. Higher-frequency effective moisture variations represented by the Black Mesa pollen curve (c) resemble middle-range dendroclimatic fluctuations.

The dendroclimatic plot (d) illustrates tree-growth departures, in standard deviation units, calculated for ten-year intervals overlapped by five years. These departures integrate relative precipitation and temperature variability from the Colorado River on the west and north to the Pecos and

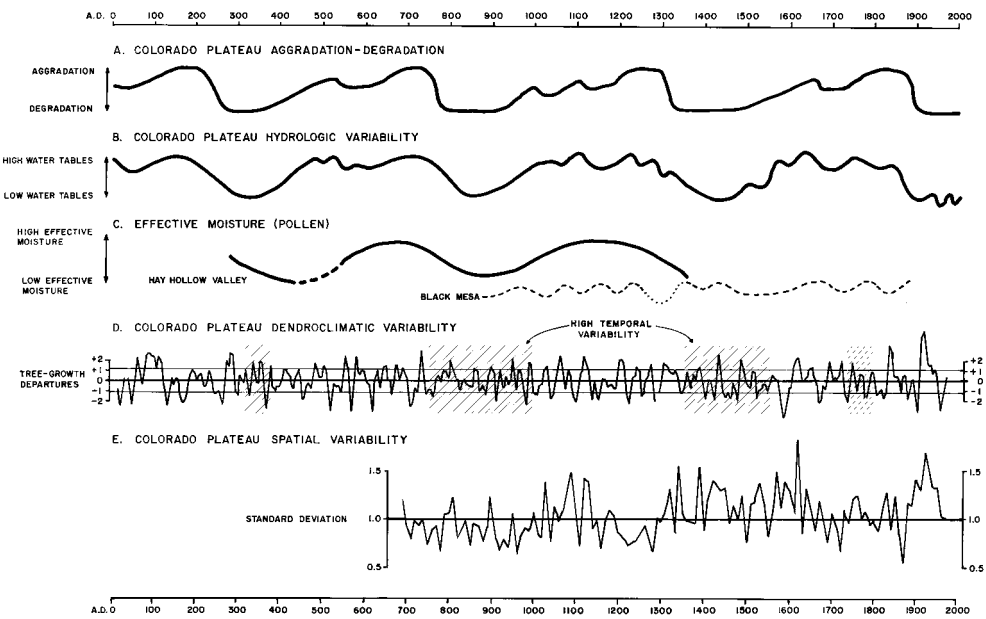

Figure 3.1
Environmental variability in the northern Southwest, A.D. 1 to the present: (A) floodplain aggradation and degradation; (B) alluvial groundwater fluctuations; (C) effective moisture; (D) dendroclimatic variability in standard deviation units by decade, overlapped by five years (hatching indicates periods of high temporal variability); (E) spatial variability in dendroclimate in standard deviations. After Dean and Funkhauser 1995: Fig. 10.
Drafted by Alison Dean.

Gila rivers on the east and south. Hatching indicates intervals characterized by high temporal variability when climate oscillated rapidly between maxima and minima. Intervening periods were characterized by more gradual transitions from low to high values. Figure 3.1(e) presents spatial variability in dendroclimate as measured by the standard deviation of departure values of the dendroclimatic stations for each decade. High values specify periods in which climatic conditions varied considerably across space. Low values indicate intervals when uniform climatic conditions prevailed throughout the region.

Principal components analysis of a geographical network of twenty-seven climate-sensitive tree ring chronologies (Dean 1996a:figs. 4, 8, and 9; Dean and Funkhouser 1995:figs. 7–9) provides additional information on spatial climatic variability. This work reveals a strong regional pattern characterized by the clustering of station chronologies into two main groups, one in the southeastern and the other in the northwestern part of the region. This configuration captures the bipartite seasonal precipitation pattern that characterizes the modern climate of the Southwest. The southeastern area is dominated by a unimodal, summer-dominant rainfall regime, while in the northeastern area a bimodal, winter-summer precipitation regime prevails (Dean 1988a:fig. 5.1). Although this pattern persisted throughout most of the

last fifteen hundred years, between A.D. 1250 and 1450 it deteriorated into a chaotic disarray that bears little resemblance to the long-term pattern. This climatic disruption undoubtedly had serious consequences for populations that had become adapted to seasonal precipitation regimes that had persisted for more than seven centuries (Ahlstrom, Van West, and Dean 1995).

Behavioral Adaptation

Major environmental changes at the end of the Altithermal, around four thousand years ago, inaugurated the general environmental conditions that prevail today in the Southwest. These conditions set the stage for the adoption of agriculture as the primary subsistence technique after the introduction of domesticated plants around 2000 B.C. Behavioral adaptation since that time has been primarily in response to variability within established environmental limits rather than to change from one regime to another.

The environmental reconstructions (fig. 3.1) identify intervals of potential environmental stress that may have affected the human populations of the region. Primary alluvial-hydrologic and effective moisture minima centered on A.D. 300, 850, 1350, and 1910 would have been inimical to agricultural subsistence systems, especially when reinforced by high-frequency stresses caused by droughts (1250–1300), high temporal variability (325–375, 750–1000, 1350–1550), and low spatial variability (750–1000). Secondary alluvial-hydrologic minima reinforced by high-frequency stresses occurred at A.D. 550 to 650, 1130 to 1180, and 1650 to 1750. Between these intervals, environmental conditions were favorable for agriculture, particularly during the 900–1130 period, which was the most favorable long interval in the last two millennia. High spatial variability in climate during this period encouraged interareal interchange among groups and facilitated the development of geographically extensive interaction systems (Plog 1983, 1984). Environmental stress on human subsistence systems would have increased in proportion to population numbers, which approached regional systemic levels by A.D. 1000 and reached local saturation levels in some places even earlier (Dean, Doelle, and Orcutt 1994).

Clear examples of behavioral response to environmental variability before about A.D. 800 are difficult to identify (Plog et al. 1988), probably because local and regional populations were low enough to make mobility a viable reaction to local environmental stress. Rather than change their subsistence practices, people were able to move to nearby unoccupied areas suitable for prevailing techniques. An exception to the early reliance on mobility is the widespread aggregation into small villages between A.D. 100 and 400 (Elson and Lindeman 1994; Haury and Sayles 1947; Smiley 1985) during severe regional droughts (fig. 3.1), which may have forced populations to concentrate in especially favorable localities. Regional population growth severely limited the mobility option after A.D. 800.

Major regional responses to environmental opportunity occurred during the especially favorable period between A.D. 900 and 1130, when populations

expanded into nearly every area of the Southwest and important cultural advancements occurred. Among the latter were the development and expansion of the Chaco regional system, which by A.D. 1100 encompassed much of the Four Corners area in Utah, Arizona, Colorado, and New Mexico (Crown and Judge 1991; Lekson et al. 1988; Vivian 1990), the development of the Mimbres pattern in southwestern New Mexico (Lekson 1990), the replacement of pithouse villages by small pueblos scattered widely across the landscape in the Kayenta and Virgin areas of northern Arizona, southern Utah, and southern Nevada (Dean 1996b; Gumerman and Dean 1989; Lyneis 1995, 1996), the replacement of the Mogollon pithouse village pattern by the Reserve phase pattern of dispersed small pueblos in the Mogollon Highlands (Reid 1989), and the stabilization of the Hohokam pattern represented by the Sacaton phase (Crown 1990).

Many of these developments ended during the environmental degradation of the A.D. 1130–1180 interval. The Chacoan regional system disintegrated, the Mimbres florescence waned, the Kayenta pattern of dispersed hamlets was replaced by the concentration of settlements in localities especially favorable for agriculture, there was a general exodus from upland localities (the Coconino Plateau, northern Black Mesa, northern Mesa Verde) and peripheral areas (the Virgin branch and Kayenta extensions in southern Utah), and the Hohokam Sedentary Period ended.

Reestablishment of favorable environmental conditions after 1180 was accompanied by the consolidation of changes that had begun in the previous period. Distinctive successors to the Chacoan system crystallized to the north (Mesa Verde) and south (Cibola) of the former core area (Stein and Fowler 1996; Varien et al. 1996), distinctive patterns arose in the Kayenta (Dean 1969, 1996b; Lindsay 1969), Hopi Mesas (Adams 1996), and middle Little Colorado (Adams 1996) areas, aggregation continued in the Mogollon Highlands (Reid 1989), and the Hohokam Early Classic pattern developed in the deserts (Crown 1990).

The A.D. 1270–1450 interval of massive low- and high-frequency environmental degradation—which involved falling alluvial water tables, severe floodplain erosion, decreased effective moisture, high temporal and spatial variability in climate, the disruption of the seasonal precipitation pattern, and the Great Drought of 1276 to 1299—was accompanied by substantial cultural transformations across the region. Initial changes involved the emergence of distinctive local patterns that were soon abandoned or replaced by different patterns. Major population dislocations involved the abandonment of the San Juan drainage by Anasazi groups who moved south and east into the Hopi and Zuni areas, the Mogollon Highlands, and the Rio Grande drainage. Cultural changes included major socioreligious innovations, such as the Katsina cult (Adams 1991) and the Southwestern cult (Crown 1994); large population concentrations in the Hopi Mesas (Adams 1996), Zuni (Kintigh 1985), and Rio Grande (Cordell 1989; Crown, Orcutt, and Kohler 1996) areas, the middle Little Colorado drainage (Adams 1996), the Mogol-

lon Highlands (Reid 1989), the Tonto Basin (Stark, Clark, and Elson 1995), and the Casas Grandes area in northern Chihuahua (Di Peso 1974); the consolidation of the distinctive Salado (Crown 1994), Late Classic Hohokam (Crown 1990), and Casas Grandes (Di Peso 1974) patterns; and the rise of large aggregated communities throughout the region.

The advent of favorable floodplain conditions and the reestablishment of the normal precipitation pattern after A.D. 1450 coincided with the restoration of a degree of cultural stability, although the patterns were quite different from what had prevailed prior to A.D. 1250. Populations were concentrated in totally different areas (Dean, Doelle, and Orcutt 1994), settlements were distributed differently across the landscape, communities were larger and more complex, new site configurations dominated, and major socioreligious changes are indicated by different architectural and artifactual forms and distributions. These patterns lasted only until European colonization brought depopulation, political subjugation, and major reorganization to the native peoples of the region.

Information Management

Human behavioral response to regional environmental variability and change in the Southwest has important implications for the roles of information management and cultural schemata in the processes of sociocultural adaptation and evolution. Although the impact of these phenomena on the archaeological record is filtered through the vagaries of individual and group behavior, the data do allow plausible inferences about the accretion of social memory and changes in environment-related schemata. These inferences are based on the assumption that significant ideational changes are likely to have accompanied the major adaptive transformations of southwestern prehistory.

The adoption of food crops around 2000 B.C. undoubtedly represented at least the beginning of major transformations in the culture-environment schemata that had governed former hunter-gatherers' means of extracting subsistence from the natural world and codified their relationships to that world. The long interval between the acquisition of domestic plants and the commitment to farming as the primary means of subsistence (Huckell 1995; Matson 1991; Welch 1996; Wills 1988) suggests that the transformation of ideologies based on food collection into ones based on food production was fairly gradual, allowing plenty of time to reconcile their inconsistencies. Hunter-gatherer social memory pertaining to the natural environment undoubtedly contributed significantly to the new schemata and indeed undoubtedly persists to the present in prescribed ways of dealing with natural phenomena.

Because of environmental factors and, perhaps, proximity to the southern sources of domesticated plants and knowledge of how to use them, commitment to agriculture appears to have occurred earlier in the desert than in

the uplands (Wills 1988). This transition appears to have been completed throughout most of the Southwest between around A.D. 400 and 800, although gathering and hunting remained part of the subsistence mix well into the historical period. The commitment to farming as the primary means of subsistence was a major, virtually irreversible change (Welch 1996) and undoubtedly involved the consolidation of ideational systems that organized, sanctioned, and harmonized the old and new elements into schemata that were qualitatively different from preceding constructs. Interestingly, the technological components of these schemata were similar across the entire region. The full range of food procurement and processing tools, techniques, and procedures was known to most groups, with these elements employed selectively depending on local circumstances. Differentiation lay not in the technology itself but in the ways in which it was organized and ideologically integrated with other aspects of culture.

The period of sociocultural growth and expansion between A.D. 900 and 1150 marked the apogee of many schemata that were closely attuned to prevailing environmental conditions. The selective fitness of their schemata allowed the Hohokam and Chacoan regional systems to expand geographically and achieve levels of sociocultural complexity unprecedented in the region (Crown and Judge 1991). Less complex societies also underwent range expansion and sociocultural developments founded on unusually productive congruences between schemata and environmental conditions. The widespread demographic and sociocultural changes that terminated these florescences to some extent resulted from the environmental degradation of the mid-twelfth century that reduced the efficacy of the schemata that regulated interactions with the external world. Particularly vulnerable were the more specialized complex societies that had approached or surpassed local carrying capacity thresholds.

The century or so that followed A.D. 1150 involved in part reconfigurations of prevailing schemata to conform more closely to altered situations. A brief florescence of distinctive behavioral patterns in the late thirteenth century undoubtedly represents the crystallizations of new schemata attuned to local conditions. The major environmental deterioration of the late thirteenth century revealed the adaptive weaknesses of these conceptions and resulted in the greatest cultural and behavioral transformations in southwestern prehistory. The human disjunctions of this interval likely reflect the partial failure of existing schemata to anticipate the altered ecological relationships and provide solutions for the adaptive problems they created. The result was a period of adjustment that eventually produced new cultural patterns capable of handling the changed situation. On the plateau, several discrete local configurations were replaced by the distinctive Pueblo IV pattern of aggregated pueblos with large plazas enclosed by room blocks (Adams 1996) and the spread of the Katsina cult (Adams 1991). The strength of this pattern bespeaks a dominant network of closely related schemata extending east from the Hopi mesas to beyond the Rio Grande. Elsewhere, other equally distinctive patterns arose, including the many manifestations

of the Salado phenomenon, the Late Classic forms of the Hohokam, and the Casas Grandes configuration, many of which participated in the Southwestern cult (Crown 1994). Versions of the schemata represented by these strong patterns stabilized after about 1450 until their autochthonous evolution was truncated by the imposition of Spanish colonial rule around 1600.

From the perspective of complexity theory, southwestern prehistory can be viewed in terms of a number of localized cultural schemata, each of which was configured at any point in time by its original composition, by the unique history of the human group that carried it, by the acquisition and incorporation of new information, and by the reorganization of old and new information into a coherent whole. Information that carried through from the past resided in the social memory of the group. New information was derived from many sources both internal and external to the system.

Geographic differences in culture origins, history, and environmental conditions and changes created numerous local traditions that, though similar to others in general configuration, exhibited consistent differences in specific aspects. Thus, although broad chronologically and geographically bounded patterns (Anasazi, Hohokam, Mogollon, etc.) developed, there remained considerable local variation within the limits of these large-scale similarities. Differences within and between large-scale patterns were major sources of the cultural variability on which selection acted to cause schemata to evolve into new patterns in response to changing adaptive situations. This process produced configurations (schemata) that succeeded for varying lengths of time but eventually collapsed in the face of systemic changes in the ecological relationships that established and sustained them. This pattern resembles the behavior of adaptive systems on coupled fitness landscapes (Kauffman 1993; Kauffman and Johnson 1992; Wills et al. 1994) in which the success of particular systems in adapting to and exploiting individual fitness loci changes the fitness potential of other localities, thereby conditioning and often limiting the adaptive potential for other systems. The general, regional trend of the selective processes, however, was toward cultural configurations that were progressively better adapted to the entire spectrum of temporal and spatial environmental variability that characterizes the Southwest.

Social Memory, Human Behavior, and Adaptation

Numerous cultural mechanisms exist to manage information crucial to a society's survival. From an archaeological point of view, this information can be viewed as a reservoir of behaviors appropriate to a variety of environmental conditions and invoked in different combinations in response to any particular circumstances or changes (Dean 1996a). The inventory of behaviors—which includes technology, subsistence practices, settlement configurations, the organization of labor, and social structure and organization—provides a society with the ability to adjust to normal fluctuations in its

natural environment. If these behaviors are broad enough, they also afford the flexibility to adapt to environmental changes that create new adaptive circumstances.

The actual use of the behavioral inventory is mediated by beliefs about the environment and its relationships to humans. A society's ideology, one of many cultural schemata, controls how knowledge, beliefs, and behavior are used and reconciled with one another and the culturally defined universe (see fig. 1.2). If schemata such as these are too specialized and constrain the implementation of appropriate behaviors, environmental change can bring about the radical change or even extinction of the society. On the other hand, schemata that activate a wide range of behaviors enhance the society's ability to accommodate change, augment its ability to preserve itself in a state acceptable to its members, and increase the likelihood of its persistence in recognizable form.

Innumerable factors enter into the composition of a group's environmental schemata. Many of these are preexisting cultural, social, and ideological elements transmitted down the generations. Others may arise through discovery, invention, borrowing, or recombining existing knowledge. An important source of a society's body of knowledge and beliefs about environmental matters is the nature of the environmental variability that served as input into the conceptual system. Not all aspects of the environment are equally observable or comprehensible. Many environmental events, such as Pleistocene glacial and pluvial transformations, happened too long ago to be preserved in the social memory of more recent groups. Episodic occurrences, such as volcanic eruptions and earthquakes, may happen so infrequently that they are lost from memory during the long intervals between events. Many more, however, occur often enough to reinforce or reimplant memories of them. As a result, the temporal structure of environmental variability is an important determinant of the information stored in social memory.

Because stable aspects of the environment are continuously observable, they are major components of any group's larder of environmental information. Southwestern groups' knowledge of stable environmental elements is comprehensive, detailed, and an important influence on daily life. Their information systems tell them where and when to find water, arable land, wild plant and animal foods, raw materials, fuel, medicinal materials, and items of religious significance and when to expect rain, drought, high winds, freezing cold, and other weather conditions. The geographic variability embedded in stable environmental elements acts as a surrogate for potential temporal variability. No matter what its dominant condition, every environment has microhabitats that represent past or potential future states. Knowledge of these special places and the ability to exploit them preadapts societies to deal with systemic changes that significantly expand conditions previously only sparsely represented (see Crumley, this volume).

Episodic environmental occurrences have varying potential for incorporation into social memory. Every society preserves information on ex-

treme events (floods, droughts, freezes, hailstorms, wild fires, insect outbreaks) and how to deal with them. Rare events may be spectacular or traumatic enough to imprint themselves on the social consciousness. For example, Hopi oral tradition retains knowledge of eruptions of Sunset Crater (Malotki 1993; Malotki and Lomatuway'ma 1987), the most recent of which occurred more than seven hundred years ago. This knowledge, however, is invoked in a moral context, and there is little evidence for specific information on how to deal with the subsistence consequences of an eruption.

Low-frequency variations, such as cyclic fluctuations in alluvial water tables and the deposition and erosion of floodplain sediments, seem not to be encoded in southwestern social memories, and the current states of these factors generally are perceived as stability. Thus southwestern societies, both indigenous and European, are adapted to the prevailing conditions of low alluvial water tables and fully integrated arroyo systems. Even the scientific knowledge that contrasting conditions prevailed in the past and are likely to recur has had no appreciable effect on Anglo economic and environmental planning and behavior. Indians, environmentalists, and land use managers behave as if floodplain conditions have always been and always will be as they are now. Thus the resumption of groundwater accretion and floodplain aggradation could have severe unanticipated consequences for the region's inhabitants. Experience with a few localities where high water tables and alluviation currently exist may endow Native Americans with greater initial flexibility to deal with the large-scale expansion of these conditions.

Social memory probably encapsulates most environmental variability controlled by high-frequency natural processes. Experience of the full range of this variation is frequent enough to reinforce these memories and allow societies to adjust readily to variation in these elements of the environment. Documented responses include postponing or canceling planting in years unsuitable for crop production, expanding planting in years likely to produce bumper crops, and spreading the subsistence risk by farming a variety of habitats, at least some of which are likely to yield under unfavorable circumstances and all of which may yield under optimal conditions (Bradfield 1971). Comprehensive knowledge of specific indicators informs the choice of farming tactics and ensures the long-term success of the overall subsistence strategy. Exploiting a wide range of habitats preserves environmental information and subsistence practices that increase a society's ability to handle environmental change. Schemata that encompass the full range of high-frequency environmental variability provide a foundation for adapting to permanent environmental change that alters the balance among the components of the adaptive system.

Geographical scale also affects the knowledge that is included in a group's social memory. Every society is familiar with the range of environmental variability that its members encounter in the course of their usual activities, and travel for trade or acquisition of nonlocal resources may acquaint them with an even wider range of variation. The amount of knowledge that can be amassed by these activities is a function of the spatial variability in the

environment. Under uniform conditions, even long-distance travel is unlikely to expand environmental knowledge. In highly variable environments, however, even daily activities can impart information about a broad range of conditions. Similarly, environmental features caused by natural processes that operate on small geographic scales are more likely to enter traditional information systems than are features caused by large-scale processes. For example, while indigenous schemata retain copious information on local weather patterns, they contain no knowledge of the global atmospheric circulation that causes the local conditions.

While social memory is a cultural phenomenon, the environmental information it contains is a function of complex interactions between human perception and information management, on the one hand, and environmental variability, on the other. Certain frequency domains of environmental variation are more susceptible than others to direct human observation and cultural transcription, and elements that fall into these domains are likely to be included in any cultural database. Patterned response to normal variation in these elements is fairly routine and provides a foundation for adapting to changes in these factors. Elements with less visible periodic attributes are less likely to be recorded in social memory. Because of the resulting paucity of cultural information, systemic change in these elements probably creates greater adaptive stress than change in more perceptible factors, with consequent greater likelihood of triggering major sociocultural change. This relationship probably accounts for the fact that most major southwestern adaptive transformations were associated with regional-scale changes in environmental factors that are so infrequent as to be excluded from traditional environmental data systems. This outcome suggests that adequate understanding of the role of social memory in human adaptation requires equal emphasis on the environmental and cultural contributions to these schemata.

Conclusions

As an essential component of the interactions between human groups and their physical environments, social memory is an important concept in the study of sociocultural adaptation to environmental change. Human societies' ideas about the natural world and its relationship to human beings heavily influence the array of behaviors available to exploit the environment, the selection of practices appropriate to specific situations, and the implementation of the chosen practices. Unfortunately, such nonmaterial aspects of culture are not directly observable in the archaeological record, in many regions the only chronicle of human activity with sufficient time depth to illuminate human response to environmental change. Thus if we wish to understand the adaptive role of information management in the evolution of culture, a conceptual foundation for linking such nonmaterial aspects of culture to the behavioral evidence preserved in the archaeological record

must be developed. Complexity theory holds considerable promise for providing the necessary connections by viewing culture as a specific kind of complex adaptive system that can be understood in terms of the general attributes that characterize all such systems.

Development of a comprehensive theory of social memory as schemata within cultural complex adaptive systems is a complicated issue far beyond the scope of this paper. However, a few elements necessary to the success of such an endeavor and a few problems that may impede progress toward this goal are clear and can be raised at this juncture.

A crucial issue is the degree to which schemata such as those embedded in social memory actually improve a society's ability to respond to environmental variability and change and thereby increase its adaptive fitness. It is one thing to describe a society's social memory but quite another to demonstrate that this aspect of culture actually enhances the group's fitness, particularly on timescales encompassed by archaeology. The fact that aspects of social memory can be traced thousands of years into the past does not by itself prove that such memory contributed to a group's survival to the present.

This consideration leads to a second: by what mechanisms do such schemata increase a group's fitness? It seems clear that social memory can serve as a reservoir of options that can be emphasized or deemphasized by positive or negative selection in the face of changing adaptive circumstances. But the question remains as to how these memories are maintained in the absence of positive selection or in the presence of negative selection. Undoubtedly their relevance to subsets of the total range of prevailing ecological conditions helps perpetuate them and in a sense preadapts them to new ecological states that arise as a result of environmental change.

A third issue is the nature of the options preserved in cultural schemata. Are they behaviors, beliefs, technologies, social relationships, language, artifacts, or, as seems likely, all these plus other elements? Does selection operate equally on these element categories, or are some more susceptible to selective pressure than others? Do linkages among element types cause some to persist simply by association with others that are propagated by positive selection? Conversely, do some adaptively neutral elements disappear through linkage with elements that are selected against? Do the acquisition, retention, and recall of information in cultural schemata have internal dynamics that are independent of selection?

Fourth, the adaptive efficacy of environmental information preserved in social memory is not always obvious. Such information often appears to have little relevance to helping societies cope with environmental variability and change, as in the case of Hopi traditional knowledge of the eruption of Sunset Crater. In fact, many aspects of modern southwestern native cultural systems seem to be maladaptive in the context of subordination to imposed governments. Understanding the massive inertia of culture, a principal function and outcome of social memory, is essential to the application of complexity theory to issues of cultural stability, variation, and change.

An important matter is how to measure adaptational success, which is

related to the question of determining on what elements selection operates. The classic biological gauge of adaptive success is species population increase. The burgeoning *Homo sapiens* population testifies to the evolutionary power of culture but reveals little about the adaptive performances of individual cultures. How significant is population increase if the nonmaterial elements that define a culture become extinct in the process? Is the elaboration of specific behaviors sufficient to identify adaptive success? Particular behaviors have spread widely throughout the world without regard for sociocultural, linguistic, or genetic boundaries. While these behaviors can be said to be adaptive successes, it is not clear that they constitute instances of cultural evolution independent of the ways in which they are integrated into viable cultural systems. Can adaptive success be measured by the persistence of cultural norms such as rules of behavior, kinship systems, and languages? That norms such as these can flourish without regard to individual cultural systems is indicated by the global spread of English or rock music across innumerable cultural boundaries. Can adaptive success be measured by the persistence and spread of cultural patterns, such as elements of the world economy that span many different cultural systems? Is the maintenance of group identity in the face of external and internal pressure an adequate measure of adaptive success? As a record (true or fictional) of past success and continuity, social memory undoubtedly contributes to this end, even in the absence of a major role in the actual physical survival of the group in question. Maintaining group identity may be a key element in the persistence of cultural schemata that logically appear to be nonadaptive or even maladaptive. Resolution of these and other questions will elucidate the nature of sociocultural systems as subsets of the more general category of complex adaptive systems.

The eventual outcome of applying complex systems theory to explaining human adaptive behavior and sociocultural evolution will hinge to a great extent on archaeological perceptions of human behavior over long time spans. Archaeology deals with behaviorally and naturally modified material outcomes (items and their spatial and temporal relationships) of past human acts, either culturally prescribed or idiosyncratic. Archaeology cannot directly observe nonmaterial aspects of culture such as beliefs, rules, ethical precepts, kinship relationships, and social obligations. Furthermore, such things usually cannot be reliably inferred from the material evidence without undue reliance on ethnographic analogy or projecting modern conditions and prejudices onto the past. Therefore the chances of directly tracking long-term changes in cultural schemata, including social memory, through archaeology are virtually zero (but see McIntosh, this volume).

Although nonmaterial and not directly apprehended by archaeology, the ideological systems that include social memory tend to produce repetitive, patterned behavior that does leave its stamp on the archaeological record. Furthermore, sociocultural evolution can be conceived in terms of adaptive behavior, a phenomenon that *is* archaeologically visible. Therefore direct

observation of schemata is not necessary to explain satisfactorily cultural stability, variability, and change. To the extent that knowledge of schemata is necessary for total explanation, however, archaeology can aspire only to incomplete success. Although the nonmaterial aspects of archaeological explanation sometimes can be fleshed out by inference and analogy, such expansions are not necessary to understand sociocultural evolution better.

Obviously, much theoretical, methodological, and analytical work must be done before complexity theory provides satisfying explanations of cultural dynamics. Many conceptual and procedural questions remain as to the fit between culture in particular and complex adaptive systems in general and as to ways in which the generalizations of complexity theory can be applied to specific human adaptive situations, especially those disclosed by archaeological records notoriously deficient in data on nonmaterial aspects of culture such as information management. Nevertheless, the progress currently being made on all these issues augurs well for future contributions of complexity theory to understanding the material and nonmaterial aspects of cultural dynamics on all spatial and temporal wavelengths.

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Part 2

Social Memory

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Chapter 4

Environmental Perception and Human Responses in History and Prehistory

Fekri Hassan

Archaeologists have often invoked climatic change as a causal factor in cultural transformation; however, the mechanisms by which climatic change influences culture remain obscure. I contend here that a consideration of how people perceive environmental change is essential for interpreting possible cultural responses. Environmental perception is a function of the past experience that is available to an adult. Such experience is framed by inherited worldviews and values and by cultural strategies of cognition and action. Perception of environmental change is shaped by the expectation of an acceptable range of variation of certain culturally significant environmental cues. Severe successive Nile droughts in the late 1700s, as well as droughts and climatic crises in 1972 and thereafter, are examples of events that stimulate an awareness of environmental change. I suggest that episodes of abrupt, severe climatic events in history and prehistory are likely to have generated an awareness of environmental change and hence might have prompted remedial or mitigating actions.

Individual perceptions and memories are subject to selective retention. Actions become a part of the social memory if they are accepted by a sizable segment of the population and are passed on to future generations. Such cultural actions are likely to become integrated in the cultural fabric of thoughts, discourse, and practice.

Cognition, Order, and Change

We live in an imagined world, and we strive to create a world that fulfills our fantasies and fancies as well as our needs for order and predictability. The airplane, the chair, the television set, and sushi are projections of thought into the domain of material production that remade the elementary materials around us into an extension of our own minds.

We project our own sense of order and explore data until we detect an

apparent realization of that order by fitting scatters of dots to polynomial equations and tortured logarithms and reciprocals (Badely 1976:273–274, on semantic organization and memory). We seek a hidden reality of order when our senses are bombarded by information that is outwardly meaningless. We search for meanings (anchoring information in an orderly system of signification) and detect/construct patterns that cohere with our expectations of orderly geometrics of both the visible and the invisible universe.

Our interactions with the world are neither passive nor uniformly promiscuous. Endowed with innate capacities inherited from our evolutionary past, we approach the world with a genetically bound epistemological grid molded by the experiences of childhood. Early experiences modulate the grid, adding shutters and modifying its lineaments, inasmuch as that is possible, within the range of the collective experiences of previous generations handed down to us by parents, tutors, childhood friends, and socializing media. Our lives gripped by cognitive grids—culturally modified and hardened—are not free from emotionally charged needs, fears, expectations, and demands grounded in our past experiences and emotional constitutions, a heritage from an ancestral life where sexual encounters or combat with predators and competitors were bonded with pleasure and pain as mechanisms to ensure that we were on the correct path of survival.

As human beings, we are far from the organisms that respond immediately or directly to the environment. We are far more complex and far less subject to environmental whims. True, we may be swept away by a violent torrent or suffer fatally from a volcanic eruption, but such events are not what shapes our relationship with our habitat. Extreme catastrophic natural events try the limits of our endurance and capabilities, but we are not daunted, developing warning systems that aim to monitor such unexpected turns of the environment. In building dams or placing a settlement on a floodplain we try to outsmart nature by determining the frequency of its disastrous events. In deciding whether to carry an umbrella or not, we make decisions on the basis of expectations grounded in a belief in a pattern (or lack of one, if you live in England) of frequency, succession, association, and telltales. The decision may also depend on the event, the distance, the possibility or preference for alternate means of protection from the rain, the way we are dressed, our status, occupation, or mood.

The realization of the possibility of rain depends on our belief in a probability assigned a value gained from personal experience or our belief in the veracity of statements by others (weather forecasts are notoriously problematic). Prediction of the probability of certain natural events is not simply a matter of personal experience or hearsay, it is often embedded in a knowledge field shaped by culturally held concepts of cyclicity, linearity, repetitiveness, contrasts, succession, stability, association, or chaos. These concepts in turn are often grounded in an emotional milieu of religious faith, divine justice, or scientific infallibility (McGovern 1994).

Attending a UNESCO workshop in Cairo, one of the key advisers to the Ministry of Public Works and Water Resources, whose charge is to forecast

future Nile flood levels, presented a model based on seven high years and seven low years, with six mid years, forming a water cycle of twenty years (Gasir 1994). He based his inference on data from 1900 to 1995, clearly changing high, mid, or low years for each cycle to fit his model (note, for example, in table 4.1 the period from 1961 to 1980, when there are two low years, not the seven of his model, nine mid years, and nine high years; from 1980 to 1994, there are seven low years, five mid years, and two high years.) The distinguished adviser confided to me during a break that his scientific model was inspired by the reference to seven years of abundance and seven years of droughts in the Koran. He was not convinced that we needed to look much further back in time than 1900 to discern the pattern of temporal variability of Nile floods. It was clear (to him) that data since 1900 indicate a twenty-year cycle and this would equally be the case far back in time. It is not clear how he chose the range of mid years, because one can manipulate the average and the range of the mode to obtain a certain number above and below the mean.

Scales of Climatic Fluctuation

The temporal variability of Nile floods has been previously examined by three different statistical methods since the seventh century A.D., a period of close to thirteen hundred years (Hassan 1981). I calibrated and adjusted data recorded from the Nile Rhoda Nilometer near Cairo to meters above sea level and made allowance for siltation of Nile bed. The results (table 4.2) show marked episodes of alternating high and low Nile flood stages. Analysis of Nile flood stages at Aswan from 1850 to 1994 reveals the episodes presented in table 4.3. The scale of these episodes is in the range of less than two decades (10–15 years), several decades (30–80 years), and more than one century (105–170 years); these compare roughly with Butzer's (1982:24) first-order, second-order, and third-order scales of climatic variations and accord with Dean's classification of high- and low-frequency events in this volume.

Butzer (1982) also recognizes variations in the range of several millennia (fourth order). These are clearly manifest in the high-order fluctuations of

Table 4.1.
Frequency of Low, Medium, and High Nile Floods from 1900 to 1994

Years (A.D.)	*Low*	*Medium*	*High*
1900–1920	8	5	7
1921–1940	7	8	5
1941–1960	7	7	6
1961–1980	2	9	9
1980–1994	7	5	2

Note: "High" = > 90 m.cu.m./year; "low" = < 80 m.cu.m./year; "medium" = 90–80 m.cu.m./year.

Table 4.2
Episodes of Fluctuations in Nile Flood Levels from A.D. 650 to 1880

Years A.D.	*Flood regime*	*Duration (in years)*
Before 650 to 1070	Generally low	
<650–930	Minor low and high	80
930–1070	Major low	140
1070–1180	Major high	110
1180–1350	Major low	170
1350–1470	Major high	120
1470–1500	Minor low	
1500–1700	?	
1710–1745	Low	35
1745–1840	High	105
1841–1880	Low	40

Hassan 1981; Hassan and Stucki 1987; Said 1993.

Nile floods revealed by the changes in the level of Birket Qarun in the Faiyum, which serves as a sensitive proxy to Nile flood heights (Hassan 1996). It is worth noting here that recognizing fluctuations at a different scale is a function of the sensitivity of a natural proxy to climatic fluctuations, as well as of the methods of investigation. Tree rings can provide a high resolution by comparison to pollen records of lake sediments. Sampling lake sediments at gross intervals with a few radiocarbon dates for interpolating age estimates can only reveal high-order fluctuations. Different statistical analysis or visual examination of a time series of annual events—for example, Nile flood records—can lead to the detection of fluctuations of different scales and account for the differences encountered in the dates of the beginnings and terminations of climatic episodes or Nile flood events. Nevertheless, different methods do reveal variations at the scales discussed above. We are thus reminded that we must be cognizant of the possibilities for consensus and divergence in the scientific recognition of natural patterns and regularities. Scientists as well as laypeople are bound to favor certain patterns because they cohere with certain domains of inquiry and previously held notions of causality. For example, a belief in the cyclicity of climatic events

Table 4.3
Short Episodes of Variation in Nile Flood Stages at Aswan from 1850 to 1994

Years A.D.	*Flood regime*	*Duration (in years)*
1890–1919	high	30
1920–1929	low	10
1930–1939	high	10
1940–1954	low	15
1955–1979	high	25
1980–1992	low	13

has led to numerous attempts to detect variations corresponding to certain astronomical cycles (Hurst 1957). Hameed (1984), for example, recognizes a signal every seventy-seven years influenced by variation in solar activity and an oscillation every eighteen years, possibly influenced by the nodal lunar tide.

Environmental Determinisim and Archaeological Discourse

In attempting to interpret how climatic variations have influenced the course of human cultural change, we are bound to encounter a variety of approaches. The role of climate in shaping culture and cultural developments is a key theme in many anthropological writings, especially following the popularization of the views of *anthropogeographie* in the seminal works of the German geographer Friedrich Ratzel (1889, 1896). During the first half of this century, Ellsworth Huntington (1915) was particularly notorious for asserting that climatic conditions and climatic change determine both the geographical distribution of civilizations in any period and the rise and fall of civilization throughout history. In archaeology, this brand of climatic determinism was tacitly accepted in many of the attempts to highlight the role of environmental conditions in shaping cultural landscapes and cultural change. The concept of *culture area* formulated by the American anthropologist Alfred Kroeber (1939), following the lead of C. Wissler (1917, 1926), is firmly grounded in the core ideas of Ratzel as well the proponents of Ratzel's position, particularly the American geographers Ellen Churchill Semple (1911) and Otis Mason (1895). Wissler, however, who suggested that natural areas in North America define culture areas, invoked prominent food sources as the environmental determinants. Kroeber, following Wissler's lead, systematically examined the relationship between environmental variables and cultural traits (Ellen 1982).

In archaeology, the concept of culture area has become the basis for professional specialization, overpowering and possibly delaying the emergence of topical specialization. For example, and in contrast, geologists specialize in mineralogy, geochemistry, petrology, vertebrate paleontology, or some other topic and do not define their professional occupation primarily on the basis of a certain region. This stems from a paradigmatic emphasis on the uniformity (universality) of geologic principles regardless of the peculiarities of any specific region and time period. Today, geologists have extended this principle of uniformitarianism to planets in outer space. Many archaeologists, however, are reluctant to discuss or consider uniform biological, cognitive, and organizational principles underlying the varieties of human cultures.

The dominant archaeological paradigm in prehistoric archaeology since the 1920s emphasizes the role of the mode of subsistence in cultural evolution. Gordon Childe's writings on the role of the mode of food production represent a bridge connecting the ideals of anthropological geography, cultural

materialism, and Darwinian evolution (Harris 1994). Childe's brand of archaeology focused less on the annals of great deeds and descriptive accounts of various cultural traits in successive historical periods and more on the role of human agency in creating a cultural world predicated on the application of technology to the extraction of production of food resources (Rowlands 1994). By emphasizing the mode of food production, undoubtedly under the influence of the world-shaking ideas of Karl Marx, Childe presented an explanatory theory of cultural evolution that has since permeated and saturated archaeological discourse. The "New Archaeology" was in essence a movement revitalizing Childe's ideas and recasting them within the guise of the scientific garb of the 1960s, in opposition to reactionary forces that hearkened to (outmoded) historical particularism, culture history, and/or art history. Regardless of the current backlash fostered by social events in Europe and the emergence of a continental philosophy hostile to what its proponents perceive as the hegemony of science and rationalism, the practice of contemporary prehistoric archaeology today still carries the stamp of U.S. materialism and cultural ecology.

Childe's work set the stage for archaeological discourse through his emphasis not only on the role of environmental conditions (which predates Childe and can be clearly seen in the Fertile Crescent hypothesis formulated by Peake and Fleure or the Oasis hypothesis first proposed by Pumpelly) but also on the role of technological innovations and social conditions as influential factors in shaping cultural evolution. The agricultural revolution and the emergence of metallurgy are two key factors in Childe's grand scheme, matched later by the emergence of cities and state societies. By emphasizing economic and social forces Childe has prepared the stage not only for ecological archaeology but also for social archaeology. In his own lifetime he underwent the changes that others between the 1920s and the 1990s have relived for themselves. No wonder both the so-called processualists and the postprocessualists vie to claim Childe as an ancestor (Harris 1994; Hassan 1994b).

At present, the glitter of continental philosophy and the euphoria of opening the doors to the hidden pleasures of talking about forbidden domains of religious ecstasies, violent origins, and the seduction of bodily experiences have created a gold rush that so far has produced a broad range of contributions from the sublime to the ridiculous. Sadly, few of the so-called postprocessualists' efforts have been devoted to tackling some of the fundamental issues that archaeologists have struggled with for the past seventy years. Religious conversion can release us from our worldly woes, but such woes continue to disturb the unwashed masses.

Seeds of Change

No clearer ground reflects the intellectual schizophrenia in contemporary prehistoric archaeology than the discourse over the role of climate and environmental conditions in shaping cultural landscapes and contributing to

cultural change. The subject is either ignored altogether in favor of more lively and chic subjects or pursued along well-trodden grounds with determination and, on occasion, obstinacy.

A glimmer of hope is on the horizon. Karl Butzer, a geographer whose textbooks and professional writings have been among the most influential in delineating the dynamic interactions between human groups and their environments, has inserted in his text (Butzer 1982) a tantalizing section on "real versus perceived environments" (252–257) in which he cultivates the seedlings nursed along the border of traditional cultural ecology (represented by the work of Brookfield 1969; Crumley 1979; Davidson 1972; Kirk 1963; Licate 1980). The following quotations cited by Butzer capture the streaks of a new ecological paradigm: "Aztec territorial differentiation resulted from a process of mental and social action. The Aztec perceived space as existential not geometrical, real not abstract, organic not neutral. In addition to man and other earthly creatures, space was inhabited and dominated by supra-human beings, who in a direct way determined the human condition" (Licate 1980:28). And, "We cannot pretend to understand man on earth without some knowledge of what is in the mind of man. . . . Decision makers operate within an environment as they perceive it, not as it is" (Brookfield 1969:75–76)

In an inspiring work by Harold and Margaret Sprout (1965) entitled *The Ecological Perspective on Human Affairs* (a modified and edited version of an original essay disseminated in 1956), one encounters the most cognitive aspect of man-milieu relationship following a section repudiating environmental determinism and a sympathetic discussion of "possibilism" and probabilistic models of behavior. Their position is expressed concisely as follows: "*Moods, attitudes, values, preferences, choices, decisions, projects and undertakings are relatable* [sic] *to the milieu through the perceptions and other psychological processes of the environed* [sic] *individual*" (Sprout and Sprout 1965:140; their italics). Relevant to their thesis is the testimonial of William Kirk, who exhorts us to "reconstruct the environmental not only as it was at various dates but as it was observed and [thought] to be, for it is through this behavioural (that is, psychological) environment that physical features acquire values and potentialities which attract or repel human action" (1951:160). This resonates with the British philosopher R. C. Collingwood's words: "The fact that certain people live for example on an island has in itself no effect on their history: what has an effect is the way they conceive of their position" (1946:200).

Both Butzer and the Sprouts distinguish between the milieu-as-perceived (which the Sprouts call the "subjective environment" and Butzer the "perceived environment") and the so-called real world, which the Sprouts call the objective or the geographical environment. Butzer (1982:119) adopted with slight modification the scheme proposed by Sonnenfeld (1972):

- The geographical environment is the objective, external, measurable, most inclusive natural, physical area of the surface of the earth.
- The operational environment is the portion of the geographical environment that impinges on man.

- The perceptual environment is that portion of the functional environment of which man is conscious.
- The behavioral (Butzer's "modified") environment is that portion of the geographical environment modified by human actions.

The formulations by the Sprouts, Sonnenfeld, and Butzer speak of a privileged position of an "objective or real environment" (Butzer 1982:253; Sprout and Sprout 1965:119). Given the philosophical quagmire of terms such as *real* and *reality*, it is perhaps best to speak of the geographical environment as the physical or natural habitat as construed and constructed by geographical discourse no more real than that of a native's but equally relevant in interpreting the interactions between people and their habitat from a multiplicity of perspectives and stances, each providing different insights that can complement, enrich, and tease the other. They cannot be placed within a hierarchical model, as proposed by Sonnenfeld, because the cosmic environment, a perceptual space, is far more overarching than a space bounded by hills and transient in time. It belongs to the realm of imagination, with its infinite possibilities that, when translated into action, can dam rivers, seed clouds, denude forests, and place lush green golf courses on Arabian sands.

The vagaries of the imagination and the opacity of mind (particularly that of the long dead) create a perennial problem for the student of the past: how to read other societies' perceptions of their environment. Sensing this difficulty, Butzer remarked: "The only way to gauge a potential perceived environment and the apparent decision-making process linking it to cultural activities . . . would be with a deductive-predictive model" (1982:257). Brookfield (1969), commenting on the problem of incorporating the environment as perceived into an empirical approach, stated three goals:

1. Descriptive simulation of generalized perceived environments,
2. Explanation of the perceived environment in terms of its information sources, and
3. Testing the simulation in terms of accuracy, resolution, depth, scope, and continuity.

I will return to this issue in the later part of this essay.

Traces of the Past

In attempting to interpret, understand, or explain the interaction between people and environment in the past we are bound to rely on relics from the past: (1) remnants from a lived existence that constitute material traces as modifications of a landscape, adding or subtracting from its natural condition; (2) physical remains of manipulated material objects whether perma-

nent or movable; (3) graphic signatures of art or scripture; (4) residues as a direct or indirect result of human activities; and (5) oral or written traditions. The discovery and incorporation of these traces in archaeological discourse is a subject of selectivity, emphasis, and interest. We are already familiar with the role of subsequent natural and cultural actions in obliterating, masking, and remodifying primary signatures. We are also aware of the gap that exists between the lived world and archaeological traces. We have often ignored, however, the field of knowledge in which the past is cultivated, overlooking the meaning of the past as an ancestral, generative, and self-making dimension of human existence. We have overemphasized, in contemporary archaeology, the abstract notions of functions of artifacts, their modes of manufacture, and their typological affinities within a subtext of regional cultural entities represented by distinct and diagnostic traces. This ancestral past serves often to legitimize certain fields of knowledge and action on the world (see the final section of this paper) and hence cannot be totally ignored.

The possibility of counting, describing, and statistically matching artifact collections can lead to complacency. In dealing with the environment, our approach at first consists of listing the types and ranges of resources as the basis for drawing inferences within a field of knowledge gained from ethnographic observation, no matter how stereotypical or partial. Advances in our own knowledge of the past from the study of phytoliths, mitochondrial DNA, tandem accelerator radiocarbon dating, computer graphics, and GIS applications have opened up new methods for selecting data that may nudge our inquiry into new theoretical domains. Nevertheless, our main concern should be devoted to the shortcomings and potentialities of our overarching knowledge field (episteme) and the implications of an explanatory strategy that continues to invoke notions of proof and objective reality with little examination of the practical impossibility of proof in a world of probabilities and the ethereal (abstract) notion of an objective reality as a necessary and knowable component of scientific knowledge.

It would be futile to undertake a new turn in ecological archaeology within the current philosophical grid of explanation. Still, it would be equally trivial to abandon the basic foundations that inform scientific inquiry and revert to the field of wild ideas, imaginative leaps, dogmatic assertions, atavistic tantrums, and nihilistic relativism.

A key notion in any scientific inquiry is that of anchoring theoretical formulations in observations. Ideals can inform observations, but without observations ideas belong to a flight of fancy, an important domain of human life and existence but one that primarily informs fiction, paintings, and mythology. The acceptability of a scientific idea is subject not only to the examination of empirical foundations but also to its coherence with a widely accepted body of scientific knowledge. In addition, ideas ought to be internally consistent. Scientific inquiry, as such, is not tied exclusively to a certain brand of ascertaining how empirical data are authenticated, or how the adequacy of a theory is judged in terms of observations, or how ideas are for-

mulated to explain a specific phenomenon, or even how logical consistency is ascertained. These are matters of strategy and tactics in scientific enquiry. They should not overpower its principal tenets, which have to do with establishing credible links between observations and ideas in order to develop sensible models and generalized notions that economically account for observations and satisfy a community of experts. The openness of scientific inquiry and its ethos of tolerance of alternate views and willingness to modify and restructure scientific models and theories moderates the potential for dogmatic assertions based on consensus. In the ideal scientific community, authority is displaced from individuals to communal judgment (in which adherence to observations and the economy of models and theories plays a decisive role).

Nile Flood Variations and Human Responses

Continuing with Nile floods as a case study for examining how we can deal with human responses in the past to environmental and climatic change, we note that several cultural developments and happenings in prehistoric and ancient Egypt have been attributed at least in part to either excessively high or catastrophically low Nile floods (Hassan 1994a).

As indicated above, statistical analysis of variations in Nile floods (Hassan 1981; Hassan and Stucki 1987) has revealed episodes of low and high floods of different scales. The perception of a change in the flood regime is difficult to predict, even today, because of the irregularity of the episodes (cycles can only be inferred after noise has been filtered out) and because the available record often covers too short a period to provide for adequate detection of the temporal pattern of episodes. Accordingly, it is clear that actions are likely to be taken in response to the recurrence of freak events in a rapid succession forcing the diagnosis of a change in climate (even if such a diagnosis is not substantiated later).

Anomalous (freak) events are judged against a so-called normal range of fluctuations much the way consumers calculate what they deem to be a fair price based on traditional past prices. Gabor and Granger (1965) indicate that a buyer will probably decide to purchase if the product's price falls within an acceptable range whose limits are related to a prevailing market price and the price at which the product is normally purchased. Uhl (1970) observed that in judging a price change consumers use as a reference point the range of prices last paid. Although other factors contribute to deciding to purchase a product (e.g., reliability and value relative to cost, urgency, availability of funds, etc.), what we are concerned with here is the tendency to determine the value for a parameter based on past experiences.

What is considered to be the normal range of variation is likely to be a function of the nature and span of an individual's experience and the normal range of variation communicated directly to the individual by trustworthy living members of the community. Considering the working experi-

ence of a young adult—say, ten years (from age fifteen to age twenty-five)—and that of an old person—say, fifty years (from age fifteen to age sixty-five), the span of active living memory of past events is likely to be in the range of fifty years and perhaps as long as a hundred years if one adds the experiences communicated by departing elderly members of society. The memory of an event such as that which led to the creation of the dust bowl in North America (Lockeretz 1978) can stand out for some time, first through personal experiences, then through direct verbal communication to children or other adults from those who witnessed it, and subsequently to future generations through accounts in textual accounts, movies, and novels (Steinbeck's *The Grapes of Wrath*, for example), until it enters the domain of myth or vanishes from memory.

The reinforcement of a freak event is likely to be a function of the intensity of deviation from the normal. This is clearly the case in the accounts of Nile floods in the annals of Al-Maqrizi (1441) and others (compiled later by Ali Mubarak [A.H. 1306 (A.D. 1888/1889)] and also Zakry 1926) in which events of Nile floods associated with famines were particularly singled out. For example, for the period from A.D. 1600 to 1800, Zakry cites the following events (I have attempted to preserve in my translation the flavor of the original):

1622 (A.H. 1031)	The Nile rose greatly (excessively), close to twenty-three cubits, and then fell and rose again another great rise, causing damage to some cultivated areas. The Cairo Canal (Khalig) was flooded for more than one hundred days, causing inflation (increase in prices).
1641 (A.H. 1051)	Nile flood stage reached fifteen cubits then fell, causing inflation and drought.
1694 (A.H. 1106)	The Nile came short then fell rapidly, leaving land thirsty and causing inflation
1704 (A.H. 1116)	The Nile stopped so people prayed for water. It increased on the eleventh day of Thot [a Coptic month] up to seventeen cubits, so some land was irrigated. It sank rapidly after aggravating inflation.
1722 (A.H. 1134)	The Nile came short this year, so prices rose in the following year.
1778 (A.H. 1192)	The Nile overflooded excessively so that roads were cut. It lasted until the end of Thot.
1783 (A.H. 1197)	The Nile came short and sank rapidly before the day of Crucifixion, so that lands in both Upper and Lower Egypt were thirsty and prices rose to the extent that the price for wheat was ten riyals [for an *ardeb*] and the hunger of the poor was aggravated.
1784 (A.H. 1198)	The Nile came short, so that the intensity of inflation was the same as the year before.
1792 (A.H. 1206)	In Mohram [an Islamic month] of this year the Nile

	fell all at once so that lands became thirsty and only a few parts were irrigated, accordingly inflation was intensified.
1792 (A.H. 1207)	The Nile fell on the tenth day before Crucifixion, the day after the low flood of the previous year, being two cubits short at the time of irrigation, so that the price of an *ardeb* of wheat reached eighteen riyals, [consequently] people ate dead horses, donkeys, and children.
1793 (A.H. 1208)	The Nile reached the average height and stayed until the first of Baba [a Coptic month]. Water irrigated most of the cultivated land because people paid attention to constructing dams, digging canals, and repairing dykes.

Historical accounts, particularly in the presence of textual means for recording events, can be particularly significant in detecting historical variations on a scale of centuries. For example, Pliny (1961:bk. 5, ch. 9) noted that sixteen cubits were sufficient to irrigate Egypt and that a flood of twelve cubits caused famine. By the end of the eighteenth century, when the French occupied Egypt, a good flood was between twenty-two and twenty-four cubits (19.31–20.03 meters above mean sea level). Al-Mas'oudi reported that in A.D. 930 a flood of seventeen cubits was sufficient. In A.D. 1240, Idrisi as well as Baghdad reported a height of seventeen cubits and three fingers as adequate. In A.D. 1400, according to Al-Maqrizi, a flood stage of eighteen cubits was required, compared with nineteen cubits in 1650, as noted by Al-Menoufi.

The change in the height of the flood stage required to irrigate all Egypt was not a function of the expansion of arable land but a reflection of the rise of the Nile bed and siltation of the floodplain. The measurements in cubits were from a standard baseline. Hence as the Nile bed grew higher because of the accumulation of channel sediments, the same volume of water was recorded as a higher flood. Without an analysis of Nile siltation patterns, however, and a separate analysis of deviation from an average flood discharge using relatively sophisticated statistical methods (see Hassan 1981), variations in the volume of Nile flood discharge would have been difficult to estimate.

Human action is likely to be in response to the recurrence of freak events, particularly those that threaten or endanger or adversely affect livelihood. Similarly, the repetition of certain freak events may create the potential for improvement or new opportunities.

For the period from 1600 and 1700, it is clear that freak Nile events deviating from the norm were in most cases low, particularly after the high flood of 1641 and before the high flood of 1800, with eight extremely low floods and one excessively high flood. This low episode not only caused famines

and inflation but also led to civil strife and revolt after a sequence of three years of low floods (A.H. 1206, 1207, and 1208) between A.D. 1792–1793.

The low floods causing a series of crises from 1694 to 1793 are likely to have created an awareness of the possibility of the persistence of such a hydrological regime. Such a perception led people to "construct dams, dig canals, and repair dykes" (as well as to pray), which ensured maximum benefits in 1799 (Zakry 1926). It is also possible to speculate that the timing of Napoleon Bonaparte's invasion of Egypt, in 1798, following the three years of famines and low Nile floods of 1792–1793 was not purely coincidental, given that Napoleon had his spies in Egypt and also given his long-standing interest in Egypt as the future capital of a world empire and its importance for his enemies, the British.

In addition, the very high floods of 1934 and 1938 may have led to a delay in changing the pattern of basin irrigation to permanent irrigation in Upper Egypt in favor, in some areas, of "double irrigation," which consists of providing water to the basins in the summer when the Nile is low and at the same time using the basins as a safety valve during the years of high floods (Al-Sherbini n.d.).

Modern governmental and public concern about climatic change may be traced back to the 1970s. Adverse climatic conditions, notably serious droughts in the USSR, India, Southeast Asia, Australia, Latin America, and the Africa Sahel, led to worldwide economic setbacks. In India and Bangladesh alone, a million or more deaths have been attributed to that drought. The Peruvian anchovy fisheries were devastated, grain supplies were depleted, and famines spread, leading to malnutrition and death (Schneider and Londer 1984).

Examination of the Nile record from 1880 to 1994 using a normalized deviation from five-year averages clearly shows that the period from 1970 to the present has been characterized by low floods (low Nile floods are associated with droughts in Africa and a decrease in temperature). Parallel to the Nile case, the anchovy in Peru, once regarded as an inexhaustible source of protein, with a catch of twelve-and-a-half metric tons in 1970, plummeted to two million metric tons within three years. Although a considerable debate surrounds the question of whether climatic conditions or overfishing were principally responsible for this damage, it is apparent that climatic factors must have played a role. In Peru, the disruption of the upwelling process that brings cool, deep ocean water to the surface is attributed to El Niño (Quinn 1993), a recurring phenomenon associated with the Southern Oscillation. In 1972 the temperature rose several degrees. Accompanying the increase in water temperature was a weakening of the upwelling of oxygen and nutrient-rich waters from below. The warmer, nutrient-poor water reduced the production of plankton, thus adversely affecting the anchovies (Schneider and Londer 1984). Said (1993:125–126) noticed a good correlation between the occurrence of El Niño and the years of low Nile floods.

An effect of shortfalls in food production as a result of 1972's bad

weather was a 3 percent drop in grain production, which was the first of several worldwide production setbacks. In 1974 total grain production dropped 4.5 percent from the 1973 yields. Bad harvests also characterized 1979 in India, while 1980 was hot and dry in the central United States, which led to low yields in summer crops. The USSR also had disappointing harvests (Schneider and Londer 1984). According to Schneider and Londer, "a relatively 'safe' margin of food security was quickly eroded in the mid-1970s and again in 1980; in more emotionally tangible terms, the images of old and young victims of food price rises and famines of the mid-1970s are still vivid and poignant. They remind us of the risks of low food security and high volatility in grain stocks and prices. These memories must not be forgotten" (1984:397). As their book was going to press in the summer of 1983, major droughts were damaging U.S. corn crops.

The alarm caused by the poor harvests of 1972 and thereafter in the mid-1970s, with its implications for the cold war and the political stability of developing nations, seems to have been the reason for the U.S. National Climate Program Act of 1978 (PL-95-367, 17 September 1978), which called for concerted national efforts in climatic research, data collection, and application. It also seems to have led to a worldwide international research effort led by UN agencies in 1979 (World Meteorological Organization 1979). The recurrence of drought in the 1980s reinforced these efforts, led to a proliferation of climatic projects, and made climatic research a fashionable subject. The images of emaciated, malnourished children is undoubtedly one of the most vivid and disturbing legacies of the 1970s and 1980s.

Archaeological Paleoclimatic Models of Cultural Change

The recurrence of bad weather in the span of thirty years seems to have triggered some cultural response because of the intensity and effect of such weather on issues of vital interest to political leaders. Clearly, in Egypt (where it is almost always sunny and balmy), Nile floods and their implications for grain production, rather than weather, must have been of concern to farmers since the beginnings of food production on the banks of the Nile and in the Delta between seven and five thousand years ago (using uncalibrated radiocarbon ages). Examining the Holocene climatic record for intervals when there was a high recurrence of droughts thus models this event. Luckily, reconstruction of Nile flood heights over the last ten thousand years is possible using the changes in the levels of Birket Qarun lake in the Faiyum as a proxy (Hassan 1996). The lake used to be fed by an influx of Nile flood water before it became disconnected in Ptolemaic times. For the mid-Holocene period, the lake levels dropped around forty-five hundred, thirty-seven hundred, three thousand, and two thousand radiocarbon years before present, corresponding to 3200, 2200, 1300, and 75 B.C. (Hassan 1996). These low Nile floods are matched by low lake levels in East Africa. They fit well the high-

resolution regional simulation of Nile flood discharge by Reid Bryson, which is based on a macrophysical thermal wind relationship, or the Z-criterion derived from the work of Smagorinsky (Bryson and Bryson 1994).

These episodes were apparently abrupt and clearly severe, not unlike the events from A.D. 1694—1793 and the droughts since the late 1960s. High-resolution radiocarbon and thermoluminescence dating as well as high-resolution palynological analysis of lake cores then can improve the precision of the timing of such mid-Holocene droughts (which must have had global and pan-African effects; see Hassan 1996). Segments of the Nile record and the meteorological record that show droughts may then be utilized as analogs for the overall pattern of interannual variability and frequency of severe droughts. These segments can provide analogs for periods under consideration. Clearly, the recurrence of droughts and the close succession of severe droughts in a decade or less marks a time of awareness and a potential for change. The cultural response may be immediate or delayed depending on the technology, the social organization, the ideology, and the links between those who are likely to detect environmental cues and those who are likely to take action. Because there is also an element of probability that may depend on the chance of choosing one act or another for no particular reason, the outcome in response to a climatic event is not likely to be the same even in regions that are culturally uniform. Hence it would be advisable not to attribute a cultural event in association or in the aftermath of a climatic disruption exclusively to that climatic event unless the dynamics of the cultural response are worked out as functions of the climatic event (see Tainter in this volume). I propose, for example, that the 3200 B.C. droughts in the Nile Valley were an important element in the steps that led to the unification of Egypt and the rise of a nation-state (Hassan 1988). Paradoxically, the low floods of 2200 B.C. are apparently to blame for the collapse of centralized government at the end of the Old Kingdom (Hassan 1997). The droughts around 1300 B.C. might have been responsible for the economic and political troubles in Egypt after the reign of Ramses II (1290–1224 B.C.). Low floods may also have been responsible for the broad-scale improvements under Roman rule in Egypt, which are exemplified by programs under Augustus (30 B.C.–A.D. 14), who ordered his army to repair and deepen canals so a flood of twelve cubits would guarantee a bumper harvest.

The effects of anomalous low Nile floods, which tend to make people aware and anxious, are likely to include the small area of all available arable land that can be effectively irrigated. Low floods may also leave as much as 75 percent of arable land dry, reduce the area available for grazing, and cause decreases in the catches of fish normally collected from flood pools following the inundation. Low soil moisture is also likely to influence the normal phenological states of plants (the growth states), disrupting vegetative, reproductive, or ripening stages. Successive droughts may also lead to the salinization of the soil as salts accumulate through capillary action in the topsoil.

Episodes of low Nile floods are also characterized by greater interannual variability than are episodes of adequate floods. This creates an increase in

uncertainty as the normal pattern of expectations is disrupted. Dust storms associated with droughts may also lead to reductions in harvest yields as grain may fall before ripening or before harvesting. A reduction in Nile floods associated with wild interannual variability may also cause entrenchment, which in turn causes irrigation problems. It may also lead to the undercutting of dykes, disrupting irrigation works.

Low yields in one year may be followed by low yields in successive years, thus depleting stored grain. People may also consume the grain normally saved for planting. Even with the centralized management characteristic of earlier days, when royal stores might serve as a savings bank, successive poor floods affecting Egypt as a whole were likely to exceed the storage capacity of the central stores. In addition, in times of famine the pharaoh and his court could not command high revenues (a function of flood stage) and hence might be unable to meet their obligations toward nonfood producers in their employ (craftspeople, functionaries, guards, etc.). They could also ill afford to import food. Local nomarchs (regional governors) might withhold revenues from the pharaoh, recognizing that it would be difficult to force them to transmit the revenues from their regions. The king might also be forced to deal with refugees from adjoining areas affected by the droughts (both the western desert of Egypt and the Sinai-Levant undergo droughts synchronous with low Nile floods). Worse, the king might face an invasion. With low revenues, increasing demands, and high expectations (given the divine role of pharaoh as provider), the authority of the pharaoh might be undermined, leading to civil disorder, disobedience, and the emergence of rival religious movements and cults.

The recurrence of famines in association with plagues, morbidity, and breakdown in social order could be perceived as a breakdown in cosmic order. This was likely to generate feelings of pessimism and fear of an apocalypse, as well as notions of future salvation at the hand of a savior. Accounts of doom and gloom when Nile levels drop belong to a theme in Egyptian literature captured by the inscription on Sehal Island in Nubia (The Famine Stela), dated back to the Ptolemaic period (possible Ptolemy V, around 200 B.C.). In this inscription, a drought lasting for seven years is attributed to the reign of Djoser. The god Khnum appears to Djoser in a dream and promises to stop the drought. In return, Djoser promises to give the temple a portion of the revenues from the area. The main part of the text is the decree giving the temple this privilege.

There is no evidence that such an event occurred at the time of Djoser. The story may be a reflection of traditions regarding the Old Kingdom (perhaps dating back to the severe droughts at the end of that period). The priests may have used this "history" to gain privileges from the king. There is even a Roman-dated text in Middle Egyptian telling how Cheops saved the country by restoring the temples (Lana Troy, personal comm.). This potential to fabricate or modify a specific event in order to create a social memory is of great importance in understanding our knowledge of past environmental events.

The resilience and persistence of the concept of the seven-year droughts is remarkable. The notion of seven years of drought became prominent in connection with Egypt in the Koran, and in the Bible (see Gen. 41:25–37) in the story of Joseph (linked to the Faiyum, where major land reclamation by the founders of the Middle Kingdom followed the recession of Nile floods during the First Intermediate). Thus not surprisingly, events that happened in 2200 B.C., forty-two hundred years ago, clearly influence some decisions on Nile water management today, as reflected by the story of the senior adviser recounted at the beginning of this paper. It is important to remember, however, that although interpretation of the past is malleable, it is not entirely fluid. With clearly stated goals and with a respect for consensus and accord, a critical attitude toward authenticity of sources, validity of evidence, and the coherence of theories to a broad range of acceptable fields of knowledge, we are likely to converge on a plausible reading of the past.

The contribution of archaeology is not simply to reconstruct the past but more to confront the present and challenge our pet theories or habitual modes of thinking and acting. Our reading of the past will vary with our concerns. My concern in this essay was specifically, as an additional step in interpreting the impact of climatic change on culture, to consider the ways in which people perceive environmental change (see McIntosh and Togola in this volume). In conclusion, however, the verses below, attributed to Djoser, bring to mind another dimension of environmental change: its links with social organization and ideology. The role of the king in Egypt was to ensure that no one went hungry or thirsty under his reign. In return for the pharaoh's attention to their needs (through offerings in the temples), the gods favored the nation with plenty. Lest the king forget, the magnitude of the calamity when the Nile fell was a theme in religious lore sustained by the recurrence of low floods throughout the history of Egypt.

I was mourning on my throne
Those of the palace were in grief,
My heart was in great affliction,
Because Hapy had failed to come in time
In a period of seven years.
Grain was scant,
Kernels were dried up,
Scarce was every kind of food.
Every man robbed his twin,
Those who entered did not go.
Children cried,
Youngsters fell,
The hearts of the old were grieving;
Legs drawn up, they hug the ground,
Their arms clasped about them.
Courtiers were needy,
Temples were shut,

Shrines covered with dust,
Everyone was in distress.
I directed my heart to the past
I consulted on of the staff of the Ibis.
(quoted in Lichtheim 1980:95–96)

This literary, moral, and social tradition has been a key element in the knowledge field of Egyptians past and present. It has sustained an effort to record the heights of Nile floods at least as early as the first dynasties, to structure the year around the seasons of Nile maximum and minimum water level, to celebrate the flood plenitude (Wafa en-Nil, the date on which the Nile fulfills its promise), and to administer taxes in accordance with the height of Nile flood.

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Chapter 5

Social Memory in Mande

Roderick J. McIntosh

All that archaeologists (and indeed many historians) have ever done is to interpret the traces of past peoples' actions on the world as those peoples perceived the world. If this is a fair mission statement of archaeology, many archaeologists are at the brink of despair. How, many ask, can we reconstruct motivations, intentions, and culturally conditioned perceptions if the subjects of the inquiry are long dead, long past any interview (see Dean, p. 110)? How does one get into the mind of the long dead? For an archaeologist, it can be particularly frightening to be asked to consider, not how past communities responded to objective climate change, not how societies adapted to objective shifts in their physical environment, but how they responded and adapted to their *perceptions* of change in the physical world.

These are issues that have bedeviled archaeologists, as well as scholars of oral traditions, since the beginnings of their disciplines. As current debates about the new subdiscipline of cognitive archaeology demonstrate (Renfrew and Zubrow 1994; *Cambridge Archaeological Journal* 1993), we are far from determining or verifying the intentionality of those who have not left written accounts of their motivations. In the case of human response to climate change, the actions of past peoples may have ultimately been on their perceptions; however, those perceptions are intimately linked to real changes, real events, in the real world. That link is known in this volume as social memory.

Social memory is ultimately culturally conditioned. Yet it is always coupled to the real world (albeit always in complex ways). There is the separate issue, then, of the researcher's confidence in her or his reconstruction of the ground rules of that linkage, and here we can observe some three hundred years of archaeologists (and social historians broadly) treading the same ground as philosophers of the social sciences (McIntosh 1996). There are some parts of the world, blessedly, where with some considerable degree of confidence we can reconstruct a deep-time trajectory for social memory. The Mande peoples of the greater part of West Africa would be bemused, if not offended, by an outsiders' suggestion that their social memory not just of climate change but of the authority of those sanctioned to deal with environmental surprise and stress does not have a very deep and distinguished pedigree.

The Mande social memory of past responses to climate change is intimately tied to the Mande notion of the "weather machine." The weather machine is the link between objective change in the climate (and in the physical landscape more broadly) and *perceptions* of that change. The notion of the weather machine has a profound continuity but is endowed with flexibility that fosters continuous adjustments. That is, the shared Mande notion of self includes not just a common narrative history and common cluster of legends about the presence of the ancestors in the lives of the living (*kuma koro*) but also the sense that Mande history is an interlocked trajectory of several core values and concepts that are continuously reinvented and reinterpreted to adjust to present-day realities. Through deep time, the values remain fundamentally true to a very ancient legacy. The notion of the weather machine, as I argue in this chapter, is the Mande expression of social memory.

As I use it here, the concept of a weather machine is a shorthand for an explanatory project that seeks to identify the crucial mechanisms that cause climate rhythms and climate change. In climate research circles, the term *weather machine* is usually confined to contemporary weather mechanics (as opposed to longer-term climate) (Mörner 1987:256), but this is a self-defeatingly synchronous use of the term. In the spirit of social memory as used in this volume, and in the spirit of the Mande sense of their own history, I use the term *weather machine* to focus attention on the causal mechanisms in a dynamic model.

In Mande the weather machine is usually a person, a Mande Man or Woman of Crisis, but it can also be a power association or other occult-charged corporate group. And the weather machine always has something to say about the future. The concept can have an element of disinterested prediction akin to the Western scientific mode. But the concept is really about who has the authority to make predictions and make community decisions. The Mande weather machine is all about who can handle, who will be entrusted not to abuse for personal gain, the (often dangerous) knowledge of climate change and (most importantly) appropriate responses in the world of social action. Disinterested prediction is the domain of the paleoclimatologist's weather machines. In contrast, prediction in Mande is never separated from responsibilities in the domain of social action. Notions of authoritative action on the world, in light of models of a reality created by or manipulated by the culture hero acting as weather machine, may be more the domain of vitalistic weather machines outside the Western scientific tradition. Such notions, however, make the critical link between climate change in the objective world and the perceived world on which people are going to act.

The trick for the student of Mande history and prehistory is to use the concept of fluid transformations with continuity explicit in the Mande view of their own past in order to develop hypotheses about linked alterations to the nature of the weather machine (social memory). In this paper, I suggest a continuous trajectory, with multiple shifts, back into the last millennia B.C.,

that is, back into the Late Stone Age. It is one thing to recognize the enduring-while-changing history of certain elements in Mande weather machines through time. It is quite another to understand what lies behind the particulars of symbols, legends, and landscape markers that are the stuff of appropriation, manipulation in legitimation sequences, and negotiations in the dynamic relations among various interest groups in society. These are the dynamics behind changes to the Mande weather machine, dynamics that are never purely random in their evolution through time. In other words, certain symbols or perceptions of the physical or social environment can crystallize social action effectively only if a deeper organizing principle gives a historical trajectory to the society's social construction of reality.

The search for organizing principles or core notions behind the change-with-continuity of a Mande weather machine must never be allowed to devolve into a historicist exercise of looking for the unchanging essences of essentially static peoples (Sanderson 1992). The historicist project has always been to minimize the influence of change and to ignore processes of social history, including the production of cultural perceptions of landscape or of climate change. Rather, my intention here, when looking to the deep-time, structured dynamism of the Mande perception of climate change is to explore what gives trajectory, what fundamentally structures the deep-time dynamism of environmental social memory. Social memory here is used to mark the bridge between the deepest values and symbolic truths of a society and the social or physical environment on which members of that society have to act. Social memory is the arena in which metaphors, symbols, legends, and attitudes crystallize social action. Social memory is the arena in which captured experience with climate change and successful adaptations, as structured by a yet deeper level of values, is actualized through community debate and decision-making processes into appropriate strategies for dealing with ongoing climate change.

For the Mande, then, the venerable concept of the weather machine has long served as the instrumental bridge linking together these several levels. At the deepest level are the society's implicit core values or notions about human nature and how the world functions. These core values become expressed, at the second level, as narrative elements of traditions about heroes and heroines who functioned as weather machines. The last level on which social memory functions is that of action on the physical and social environments and ultimately the imprints of that action on the material world, imprints that archaeologists can verify on the ground. This final, instrumental function of the social memory cannot be separated from its first, ideological function. It is a core assumption of this essay, then, that social memory is the agent for change as well as the instrument for deep-time persistence in the process by which social perceptions of climate and landscape change are created. Social memory becomes the engine that powers both the workings of and transformations to the weather machine.

I believe that the Mande provide a clear example of how social memory

functions to bridge these three levels. I will argue that there may be more than simple coincidence to the apparent parallel of mode shifts in the paleoclimate of greater West Africa and the mode shifts (cumulative transformations) of essential notions of Mande authority. I certainly do not argue that they are in lockstep, and neither do I wish to imply that the often abrupt onset of climatic mode shifts stimulated metastable leaps in Mande values. I do believe, however, that climate mode shifts have been integral to a complex succession of crises that were the framework for eventual mode shifts in the nature of decision making.

Finally, social memory is not epiphenomenal. In the real world, the process by which social memory guides the society through crises is expressed as a persistent yet ever-evolving Mande resistance to centralization and the emergence of coercive hierarchical power (McIntosh 1998a). In other words, the long history of the Mande is the long evolution of heterarchy (R. McIntosh 1993a, 1999; S. McIntosh 1999), which, as Crumley (1994b:12–13; 1995:3–4) and Hassan (1994:156) remind us, creates the flexible and changing social landscapes that are very often more responsive to climate change than are the highly centralized decision-making structures of states.

The Mande needed to be highly attentive and highly flexible in their responses to the exceedingly complex, variable, and unpredictable continental West African climate. That is why it is so important for us to understand the essential notions or values of authority that enabled the Mande to persist and indeed to thrive over several thousand years of mode shifts in the nature of that climatic unpredictability (modes of ecological crises). To begin, I will define who the Mande are and look briefly at the record of climate in the vast Mande lands of West Africa over the past five to seven thousand years.

Mode Shifts of West African Climate

Mande refers to a large group of ethnically diverse peoples who speak related languages of the Niger Congo linguistic classification and share, to a greater or lesser extent, a constellation of beliefs, legends, and symbols related to their origins and an occult landscape. The major groups are the Malinke, Bambara, and Soninké, and there are innumerable smaller brethren, as well as neighboring non-Mande speakers, who share many beliefs (for example, nearby Dogon, Serer, Songhai, and even Fulani). The Mande cover most of West Africa, from the wooded savanna just north of the southern forest to the edge of the Sahara, from the Atlantic to the great bend in the River Niger (fig. 5.1). This flat, generally monotonous land can also be called Mande (or Manden). It has attracted the attention of paleoclimatologists because a large part of the territory is the Sahel, site of the terrible Sahel drought that began in the late 1960s and continues (in a weirdly modified form after about 1985) to today. The Sahel of the Mande (and West Africa broadly) is in the grip of a unique interaction between atmosphere and land, because it is adjacent to

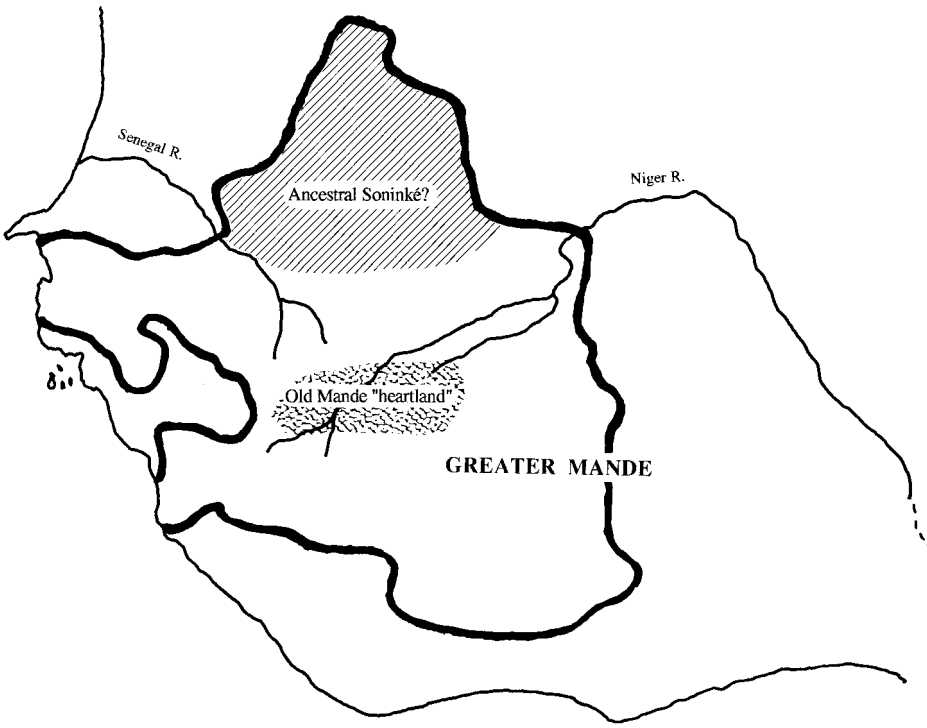

Figure 5.1. Mande in West Africa.

the world's largest desert, because it is the world's largest contiguous continental surface without significant mountains, and because anthropogenic increases in albedo and dust circulation have had a demonstrable effect on the production of anomalous drought conditions as part of artificial instabilities or metastabilities at the borders of the vast Sahara (Charney 1975; Shukla 1995:45). Indeed Mande enjoys a dubious distinction: "There is no other region of the globe of this size for which spatially and seasonally averaged climatic anomalies have shown such persistence" (Shukla 1995:44). Translated into human terms, this is a highly volatile, highly unpredictable place to live. For the historian and archaeologist, it is a superb laboratory for looking at the workings of social memory. And the high publicity of the Sahel drought, the historical accident of a superb colonial and postcolonial set of instrumental temperature and precipitation records, and the very nature of the climate volatility and anomalies have come together to attract an active set of paleoclimatologists interested in the boundary conditions and internal and external forcing mechanisms behind climate change in the region.

More than a decade ago, paleoclimatologists' elder statesman Rhodes Fairbridge wrote that the field was on the brink of a "break-through recognition" of the causes and rhythms of global climate change through planetary orbital modulation and solar radiation (1986:143). Fairbridge's prediction has been amply realized in the study of West African climate trends at the orbital or geological (intermillennial) timescale and, at the other extreme, at the instrumental, or interannual and interdecadal, perspectives. Between

is the intercentury and near-intermillennial (recent Holocene) timescale that will be of most interest here. Sadly, this last lags behind the geological and instrumental because of problems of chronological resolution (certainly compared to the American Southwest sequences [see Dean in this volume]) and because of a paucity of intensive regional data collection campaigns.

Intermillennial trends in West African climate have been studied by a number of international teams, principally those relying on evidence from deep-sea cores in the eastern tropical Atlantic, off the western and southern coasts of the subcontinent (deMenocal 1995; deMenocal, Ruddiman, and Pokras 1993; Moulin et al. 1997). This record reaches back some twelve million years (myr). These researchers have come to broad consensus about a number of issues:

1. For West African continental and eastern tropical North Atlantic climates, the complexity of the tropical ocean-land-atmosphere connection is reaffirmed, particularly in the mercurialness, or abruptness, of mode shifts (see Stevens 1995, 1997). This is particularly the case for local feedback mechanisms that can intensify or prolong climate anomalies that may have had their origin in larger orbital or insolation (incoming solar radiation) cycles or events (Nicholson 1994:124, 129).

2. High dust content in the cores does not necessarily correlate with the $\delta^{18}O$ maximum. That is, continental deterioration, as measured by dust as a proxy for aeolian erosion, does not necessarily come at maximum aridity (as measured by low temperatures as a proxy) and more probably marks high landscape destabilization at the beginning of arid trends (deMenocal, Ruddiman, and Pokras 1993:226).

3. West African aridity is certainly linked to the growth of upper-latitude ice volume, but the stronger correlation is with changes (especially North Atlantic cooling) of sea surface temperatures (SST) (deMenocal, Ruddiman, and Pokras 1993:209, 224–226; deMenocal 1995:53).

4. At the orbital or geological timescales there are statistically strong correlations of North Atlantic SST variability to Milankovitch cycles (orbital parameter changes) and insolation cycles (Broad 1997; Kutzbach and Otto-Bliesner 1982; Kutzbach and Street-Perrott 1985; Schove 1987). These correlations are patterned in distinct modes (for example, ≥ 2.8myr "Pre-Ice" [going back to 12myr]; 2.8–1.7myr "Syn-Ice"; and ≤ 1.7–1.0myr transitional [?] Holocene modes), in which researchers detect differential predominance of the 100kyr (thousands of years), 69kyr, 41kyr, and 23–19kyr insolation and orbital periodicities (deMenocal, Ruddiman, and Pokras 1993:209–219, 229; deMenocal 1995:55).

At the other timescale extreme, that of interannual and interdecadal trends, the tragedy of the Sahel drought has stimulated enormous work with the surprisingly complete annual precipitation instrumental records. (These are available on the Web sites http://nic.fb4.noaa.gov/products/assessments/assess_96/sahel.html and http://www.ncdc.noaa.gov/cgi-bin/ghcn/precip.ghcncgi.) This work is driven by the following questions

(H. Rowe, pers. comm., 1998): What are the causes of drought in arid West Africa (the Sahel, in particular)? On what timescales do humid and arid phases occur? And what are the forcing mechanisms responsible for climate change during the present century, during the past five centuries, back to the beginning of the present millennium (that is, the Medieval Climate Optimum of Europe), and during the past dozen millennia (late Holocene)? Research has gone down two intimately coupled tracks: looking for global teleconnections and looking for the boundary conditions and nearby forcing mechanisms responsible for anomalous Sahelian precipitation.

Unusual ENSO (El Niño–Southern Oscillation) activity of the 1980s and 1990s has of course stimulated much of the speculation about global teleconnections to West Africa climate oscillations. Behind such work is the hope that some securely dated, intercentury-scale climate phenomena somewhere will serve as proxy data for Sahelian precipitation. Researchers have looked (so far without great success) at European and Mediterranean Basin data sites that might be causally linked to the Sahel because of the demonstrable influence on both of the North Atlantic Oscillation (NAO) (Moulin et al. 1997:693). There is some disagreement as to the extent and degree of proximity of influence of the ENSO itself on West African continental aridity, such that high-resolution El Niño chronologies from Peruvian clerical records or Galapagos Island coral cores (inter alia) might be useful proxy data (deMenocal 1995:56; Druyan and Koster 1989; Folland, Palmer, and Parker 1986; Lamb and Peppler 1991, 1992; Nicholson 1989; Nicholson 1995:48; Ward 1992:464–467). A newer line of inquiry with good initial promise for postdiction explores connections between Sahel precipitation anomalies and (western) Atlantic hurricane activity (Landsea and Gray 1992; Rosenthal 1965; Zebiak 1993).

Perhaps more progress, as measured by emerging consensus among researchers, can be seen in the use of instrumental records to look for spatial and chronological patterns in African (and specifically, Sahelian) precipitation and overlying air mass characteristics and then to speculate about formal causal links to ocean-atmospheric variability in the nearby equatorial Atlantic Ocean. There is now a vast literature with some real high points:

1. Sharon Nicholson has compiled large-scale (continental) rainfall variability patterns into six reoccurring precipitation patterns or "anomaly types" (1986, 1994; see fig. 5.2). She believes many of these had recycled at least into the nineteenth century and possibly even throughout the present millennium. These spatiotemporal anomalies switch from one to another as classic mode shifts.

2. Ninety percent of arid West Africa's rainfall comes from the annual north-south migration to between 15° N and 19° N latitude of the Intertropical Convergence Zone (ITCZ). A number of studies have looked at variability in the latitudinal position and in the attendant rainfall intensity (by latitude). This is being done with a view to identifying correlations with eastern tropical Atlantic variables (atmospheric and oceanic), such as SST (at different

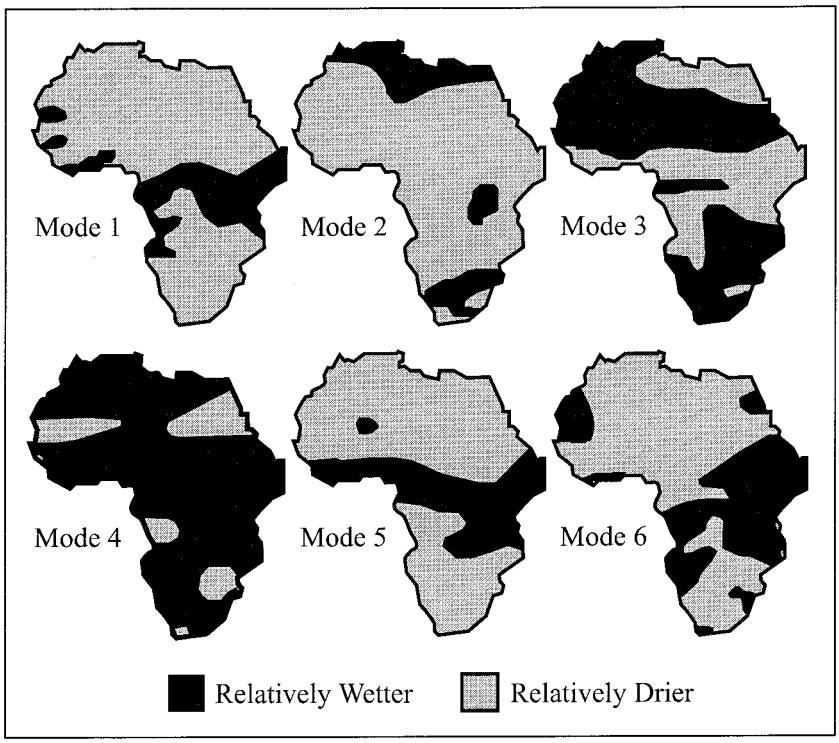

Figure 5.2. Sahel rainfall anomaly types (after Nicholson 1994).

positions), coherence of the Hadley cells, strength and position of the African easterly jet and northeasterly trades, and sea level pressure (SLP), especially associated with high-pressure cells of the NAO resting over the Azores (Druyan and Hall 1996; Folland et al. 1991; Fontaine and Janicot 1992, 1996; Janicot 1992a, 1992b; Lamb and Peppler 1992). Sahel droughts can be brought on (or at least positively correlated with) the following: a basinwide SST anomaly pattern characterized by lower sea surface temperatures in the northern Atlantic (between 10° N and 25° N) and higher SSTs in the Gulf of Guinea; stronger surface wind circulation over the north tropical Atlantic; displacement southward of the low-pressure trough where the northern and southern hemisphere Hadley cells meet; decreased coherence of the northern Hadley cell; increase in the SLP over the Azores and North Africa–northern Sahara, resulting in increased anticyclonic activity (desiccating) and increased winter northeasterly trades (further pushing the ITCZ to the south). These results truly represent "break-through recognitions," such that some now speak of a potential for effective prediction months in advance of an oncoming Sahel drought year (deMenocal, Ruddiman, and Pokras 1993:224; Folland, Palmer, and Parker 1989).

3. We can begin to see a hint in the literature (e.g., deMenocal, Ruddiman, and Pokras 1993:225) not just of discrete and successive climate modes but also of episodes of very high temporal variability (HTV) and/or high amplitude variability (HAV), such as we know from the higher-resolution

American Southwest record (Dean 1996:fig. 3; see also his contribution to this volume). For example, even though the Sahel drought has not formally ended, interannual precipitation since around 1976 has oscillated far more than during the period from 1950 to the mid-1970s.

4. Last, and most critical for the Mande, who must live with this climate regime, even during periods that cannot be formally characterized as those of HTV, West African climate is perhaps the world's most variable (Koechlin 1997:12–18). Figure 5.3 shows the extent of interannual precipitation unpredictability at a typical Sahelian location in the heart of Mande country (Goundam, Mali, at 16°40′ N). Figure 5.4 shows that the mean coefficient of variation increases significantly with declining mean annual rainfall (that is, at the upper reaches of the ITCZ's annual migration). Unpredictability and high interannual variability have obvious implications of risk and surprise for the peoples of these lands (Delville 1997:149–57; R. McIntosh 1993a, 1998b).

To summarize the bigger climate trends revealed by the long-term, geological timescale research and by the interannual and interdecadal records, the Mande have apparently always had to deal with the following climate rhythms: Normal West African climate is unusually variable, temporally and (we presume) spatially. Precipitation anomalies fall into well-defined modes, and the shift to a new mode can be abrupt. Sometimes the mode shift boundaries are marked by episodes of high temporal and/or amplitude variability (which may, in fact, be the metastable rumblings anticipating an upcoming mode shift). Local feedback mechanisms intensify or prolong major climate anomalies. And there are clear but highly complex teleconnections to ocean-atmospheric variability in the nearby equatorial Atlantic Ocean and also to more distant global SLP-SST oscillating systems (such as ENSO). These patterns show up broadly in the middle leg of West African

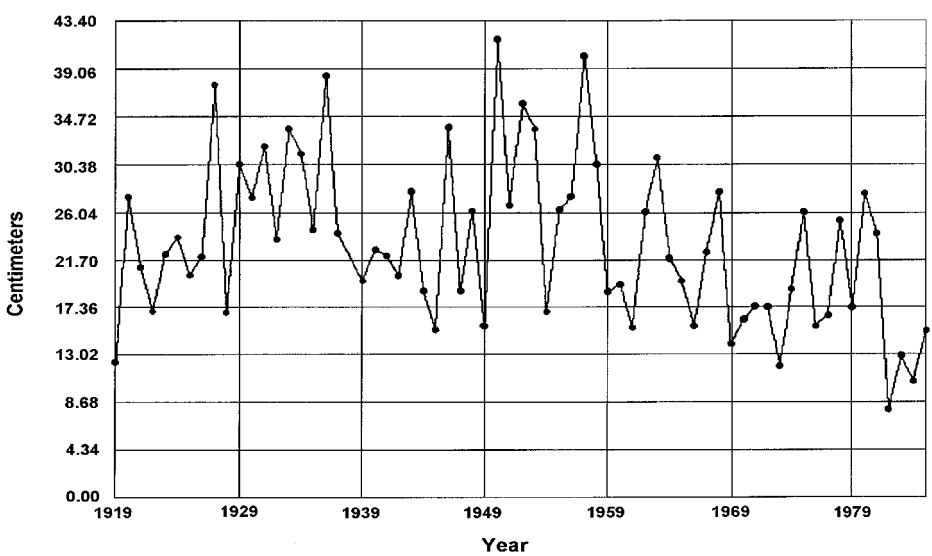

Figure 5.3. Total yearly precipitation, 1919–1985, Goundam, Mali.

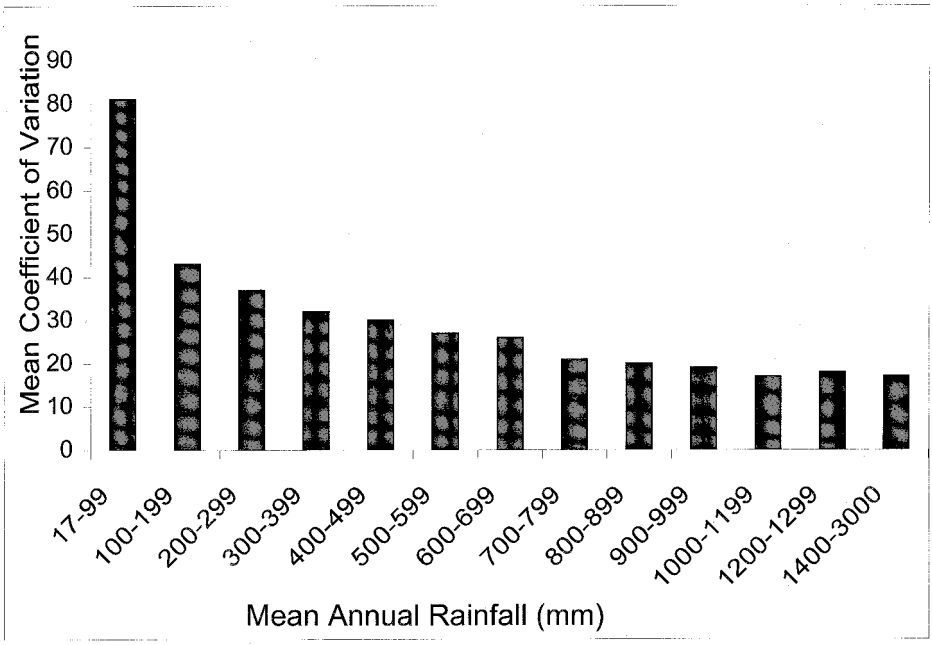

Figure 5.4. Variability of annual rainfall.

climate dimensions, the intercentury and near-intermillennial trends that, along with interannual and interdecadal variability, are the domain of Mande social memory.

Knowledge about climate change at these timescales began to come together with a resolution useful to archaeologists in the late 1960s and 1970s. Robust African data, principally from Saharan and East African Rift lake-level sequences, showed broad synchrony across the continent of major (and often abrupt) humid and arid phases back to twenty thousand years ago (Grove and Warren 1968; Livingstone 1975; Nicholson 1976, 1980; Rognon 1976; Rognon and Williams 1977; Street and Grove 1976, 1979). These African data were inserted almost immediately into the first-generation high-precision general circulation and forcing mechanism models that began to appear in the very early 1980s (Kutzbach 1981; Kutzbach and Otto-Bliesner 1982; Kutzbach and Street-Perrott 1985; Nicholson and Flohn 1980). They remain a mainstay of recent modeling (COHMAP Members 1988; Street-Perrott and Perrott 1993; Wright et al. 1993).

From the Sahara up to 24° N. and south to the heavily wooded savanna of West Africa, the intercentury-scale paleoclimatic proxy data range from locally quite excellent to highly problematic or nonexistent. The closed-basin lake-level sequences (with fine limnological and diatom data) are world classics, particularly those from the meteor crater rain gauge Lake Bosumtwi (Talbot and Delibrias 1980; Talbot et al. 1984), Lake Chad (Durand 1982; Maley 1981; Servant and Servant-Vildary 1980), and the Malian Sahara (Petit-Maire 1991a; Petit-Maire and Risier 1983). Less well developed but

ultimately destined to be critical for high-precision dating of human response is the geoarchaeology of the Middle Senegal Valley (McIntosh, McIntosh, and Bocoum 1992) and the various Middle Niger basins: Azawad (Petit-Maire 1986, 1991a, 1991b; Petit-Maire and Risier 1983), upper Inland Delta (Jacobberger 1988; McIntosh 1983; McIntosh 1995; see table 5.1), and the Méma (MacDonald 1994; Togola 1993, 1996). Dendroclimatology awaits discovery of even a single cooperative species.

The Saharan and West African Holocene climate sequence has been synthesized (with periodic updates) in a form digestible by archaeologists by R. McIntosh (1993a), S. McIntosh and R. McIntosh (1983, 1988), Muzzolini (1985), Nicholson (1980), Petit-Maire (1984, 1986, 1991a), and Vernet (1995). Recent climatic work has not dislodged this essential synthesis, and it serves as the basis for the broad arid-humid trends discussed here (fig. 5.5). Emerging strongly are issues of periodicities at different timescales as well as alternating tempos and strengths of environmental pulses, issues of critical importance to the study of populations and subsistence shifts in semiarid regions such as the northern Mande Sahel and Sahara. There, arid-humid periodicity would be expressed as environmental pulses that local communities responded to by north-south-north migrations along paleochannels or by repetitively adjusting their exploitation habits (McIntosh 1993a:198–201).

This is the issue of successive climate modes, how they come to pass, and how human groups recognize and respond to them. How do we recognize when climate change goes beyond local redistribution of heat, beyond global teleconnected cycles, and into the realm of true climate discontinuities of the order predicted by a dynamic metastable equilibrium model? Bradley (1985:13–14) describes these as distinct modes differentiated from short-term or stochastic variation by steplike changes between stable interludes. His term for the frontier of these episodes is "catastrophic discontinuities." In this volume, Dunbar speaks more broadly of fundamentally different "stable" and "unstable" climate modes and about the difficulties of discerning true abrupt mode shifts from clusters of phases within normal cyclicity.

From an Africanist perspective, the idea of climate mode shifts makes perfect sense. Such shifts would coincide with the "nickpoints," or abrupt transitional events, requiring rapid cultural change and adaptive innovation (Hassan 1996, 1997). Not immediately relevant to this chapter are three earlier Holocene modes of Saharan–West African climate: (1) Oscillatory Transition, around 11,500 to 8000 B.C., from (last glacial) hyperarid to warm and wet; (2) II. First (Cool) Holocene Pluvial, around 8000 to 6000 (or perhaps 5500) B.C., the first (stable) cool Holocene pluvial (high lakes), ending between 5000 and 4500 B.C. in a long and catastrophic dry episode); and (3) Second (Warm) Holocene Pluvial, 4500 to around 3000 B.C., a tropical-monsoonal and warm second Holocene pluvial, with highly seasonal rains and clastic profiles in wadis and lakes. It is really with the beginning of the fourth mode that, I believe, the challenge to fundamental Mande notions of authority kicks in. We begin at that interval.

Table 5.1
Middle Niger Climate Sequence

Period	*Conditions*	*Middle Niger Landforms*
mid-late Quaternary	Alternating wet-dry	Laterite covering older alluvium at MN periphery and Boulel ridge
40,000–20,000 B.P.	Pluvial (arid intervals)	Deeply bedded alluvium within all basins
20,000–13,000 B.P.	Hyperarid (Ogolian)	Massive parallel dunes (Ouagadou, Bara, Aklé); many basins deflated
Holocene I. Early Holocene	**Oscillations**	**HIGHLY UNSTABLE**
13,000–10,000 B.P.	Severe oscillations	Dune reddening begins
Holocene II. First (Cool)	**Holocene Pluvial**	**STABLE**
10,000–7500 B.P.	Pluvial	Paléo-Débo (?) covers southern basins; Niger and Bani meander; rivers deposit deep alluvium and high levees; river breaches Erg of Bara; (Fala de Molodo flows into Hodh?)
ca. 8,000 B.P.	Dry millennium	First white-yellow dunes
Holocene III. Second (Warm)	**Pluvial**	**MODERATELY STABLE**
6500–5000 B.P.	Pluvial	Niger-Bani find present channels
Holocene IV. (Transition to Present Conditions)		**QUITE UNSTABLE**
4500–4100 B.P.	Dry	White-yellow dunes
4100–2500 B.P.	Rapid oscillations decline to progressive pulse	Dunes and levees reworked; many lakes and swamps disappear; disorganization of stream networks; recharge of paleochannels
Holocene V. Big Dry	**STABLE**	
300 B.C.–A.D. 300	Dry	Irreversible desertification of Azawad; (First occupation of Macina and Upper Delta?)
Holocene VI. Recent Optimum	**STABLE**	
A.D. 300–700	Improving precipitation	Expansion of distributary system
A.D. 700–ca. 1000	Optimal conditions	
Holocene VII. High Unpredictability		**STABLE**
A.D. 1000–1200	Rapid oscillations	
A.D. 1200–1550	Severe droughts	Further degraded distributary system
ca.A.D. 1550–1630	Wet (with dry interruptions)	
(1592, 1616, 1618–1639	high flooding)	
ca.A.D. 1630–1860	Generally dry	
(1640–1644	severe drought)	
(1670s and 1680s	severe drought)	
(1738–1756, 1770s, 1790s	severe droughts)	
(1820–1840	sustained dry)	
(1860? to early 1900	wet phase)	
(most of 1910s	drought comparable to Sahel drought)	
(1950–1958	wet phase)	
(1968–[1985]	Sahel drought)	

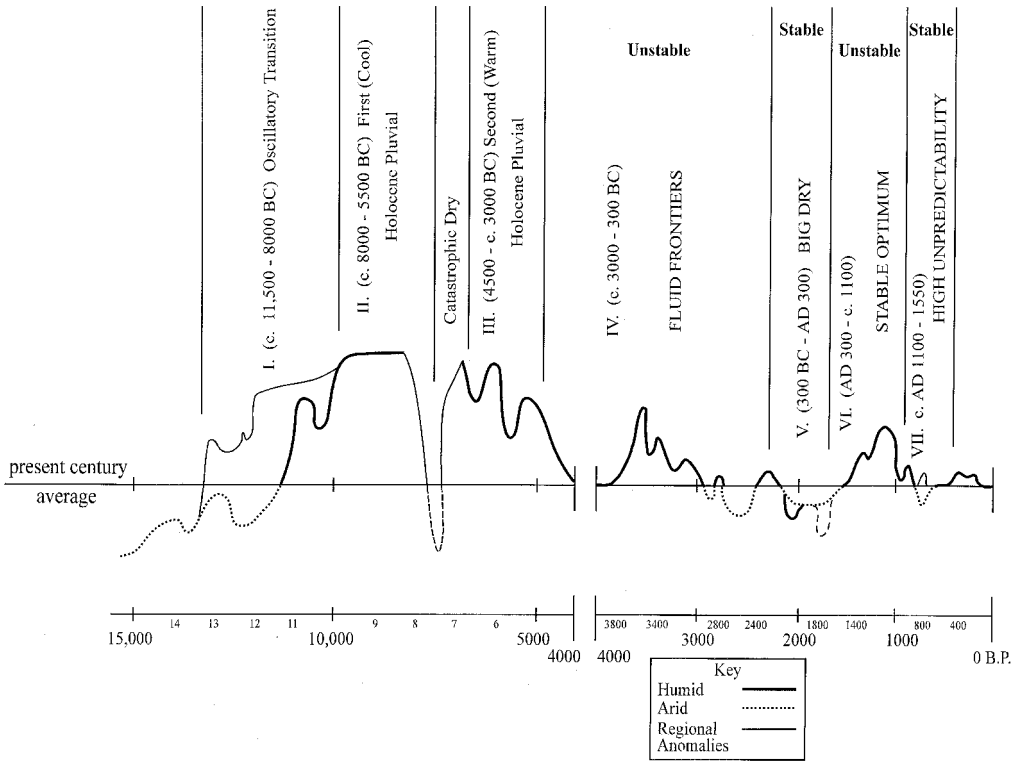

Figure 5.5. Climate curve.

Mode 4 (ca. 3000 to 300 B.C.): Fluid Frontiers

Mode 4 is characterized by a highly variable climate overall, declining to present conditions sometime in the first millennium B.C. (Vernet 1993, 1995:106–130; MacDonald 1994, 1997; McIntosh 1998a:66–80). In the physical world, *fluid frontiers* refers to the oscillating lake and playa shores, rainfall isohyets, summer ITCZ migration maximum (and positions of the southernmost Saharan massif Mediterranean rains and desiccating anticyclones). In the social world, the term *fluid frontiers* refers to mass movements of people throughout Greater Mande. The period witnessed autocthonous peoples from the heavily wooded south colonizing lands to the north, the perhaps total abandonment of former playa lands of the Saharan Azawad and Mauritanian Hodh, and the late colonization of the rich Middle Niger alluvium. All the climate oscillations would have made these the prime three millennia for pulse migrations of Late Stone Age (and by the middle of the first millennium B.C., early Iron Age) peoples and for the latitudinal slipping of the environmental zones to which they would have had to adjust. But the defining characteristics of this mode were dramatic oscillations of the 10^2 (interdecadal) and 10^3 (intercentury) timescales. For the prehistoric man or woman on the spot, this meant unpredictability.

It is hard to know exactly when this mode began. Dramatic increases in climate oscillations occurred all around the globe, but in many places they were not recorded until 2750 or even 2400 B.C. I have selected the somewhat arbitrary date of 3000 B.C. because the Saharan lakes had begun to decline by that date. The decline was from full lacustrine to semipaludial and not yet to dry playa conditions. But by 3000 B.C., the contrast was sharp enough with the preceding second Holocene pluvial. There is considerable support from distant, global events. Kutzbach (1987:257) dates to 3000 B.C. the end of his African-Asian "strong monsoonals" that began as early as 10,000 B.C. The Nile and Ethiopian lakes fell in 3050 B.C. from their previous high levels, a change corresponding loosely to the wet European Atlantic period (Hassan 1991:1144, 1997:221; Hassan and Stucki 1987). The rising and declining Saharan lakes of the third and second millennia B.C. were paralleled (if not exactly in phase) by a highly unpredictable Nile, especially from 1930–1150 B.C. and 1070–332 B.C. (Hassan 1994:174–175). Hassan (1997) suggests large-scale, time-transgressive changes to the African monsoonal system beginning in the early fifth millennium B.P. and marked by a cluster of abrupt nickpoint events at around 2500 B.C. and 2000–1700 B.C.

Elsewhere, there is equally strong evidence for unstable global climate. Southeast Asian lowland tropical arid episodes began perhaps with the 2400 B.C. return to the present position of sea levels (Maloney 1992). Lamb (1982:131–135) calls the period 4000–2000 B.C. (most likely 2500 B.C.) a global turning point, with the 3300–2800 and 1500–1300 B.C. periods characterized by neoglacial activity. The Negev dries and the Dead Sea dropped a hundred meters in 2400 B.C. (Issar 1995:354). Weiss et al. (1993:1002) attribute the decline in 2200 B.C. of the northern Mesopotamian Subir civilization to extreme climatic distress (lasting some three hundred years) (see critiques by Butzer and Hassan, reported in Abate 1994:518). Finally, some time after 4000 B.C., the Amazon began a series of significant arid episodes, each lasting several centuries until a very long dry period beginning in 500 B.C. (Meggers 1991:4, 9, 1994).

Most of these structural climate shifts began several centuries after 3000 B.C. and a few some centuries before. It is difficult to know if this gap is simply an artifact of highly spotty or poorly dated paleoclimatic data or if it suggests important regional dynamics in the global coupling of the atmospheric-ocean system. Significantly, the onset of novel instability of the Saharan lakes coincides roughly with Landscheidt's (1987:427–429, 437) Sumerian (sunspot) Minimum of around 3200 B.C. Mode 4 includes three of his other grand minima: the Egyptian (1369 B.C.), the Homeric (ca. 800 B.C.) and the Greek (ca. 400 B.C.). This distribution of supersecular solar events may suggest that the Fluid Frontiers mode will someday have to be subdivided. At the resolution with which we can currently observe climate in the lowland tropics of the Sahara and West Africa, however, it makes more sense to look at this as a significant clustering of events of great stress for human populations.

This perspective emphasizes that while at the 10^4 timescale there is an overall decline in climate (total surface evaporation, resulting in no lakes, no

swamps south to 23° N by 2500 B.C. and down to 20° N by 1500 B.C. [Petit-Maire 1986:372]), there were also periods of up to a few centuries in duration when conditions approached those of the previous pluvial. The challenge to human adaptive strategies was at a maximum during these three millennia and so too must have been the need for the affected societies to retain memories of successful responses to situations more distant than sixty years past. At the end of this mode, at around 300 B.C., the communities had to respond to yet another significant mode shift.

Mode 5 (ca. 300 B.C. to A.D. 300): Big Dry

During mode 5, West Africa was overtaken by a stable, very dry period of something over a half-millennium in duration. The last of the Saharan lakes were long since dry, and sedentary peoples moved for the first time into the fertile floodplains of the Middle Niger and Middle Senegal Valleys. Mörner (1987:257–266) takes this period as a centerpiece of his geodynamic model, arguing for a major abrupt event at around 500 B.C. He calls this the "(–)2.5°C event," in contrast to the "(–)1.0°C" Little Ice Age. Ice cores confirm that in the upper latitudes the periods from 300 to 100 B.C. and A.D. 350 to 550 were colder than the Little Ice Age.

Support for a stable shift comes from many places. From 600–500 B.C. until A.D. 300 the Amazon suffered a major dry period, and there is a major hiatus in the archaeological record (Meggers 1991). This is a period of reduced Nile discharge (Hassan and Stucki 1987:45), but the Negev blossomed, and Nabatean urbanism flourished in the desert (Issar, Tsoar, and Levin 1987:536–538).

On present evidence, the Big Dry was remarkable for its stability. By A.D. 300 or shortly thereafter, precipitation began to improve slowly and steadily, resulting in a stable improvement throughout much of the first millennium A.D.

Mode 6 (A.D. 300 to ca. 1100): Stable Optimum

The beginning point for mode 6 is more securely dated than its end. The West African lowland tropics showed none of the deep arid interludes of the Amazon (A.D. 500, 800, and, especially catastrophically, 1000 [Meggers 1994]). Improvement appeared to be steady until around A.D. 700, at which point precipitation remained relatively high until around 1100. Lamb (1982: 158–159) documents the general European warming trend after A.D. 300 to a warm maximum in A.D. 1200 (but with significant glacial restarts as well, at 500 and with some frequency from 800 to 1200).

There is some temptation to end the Stable Optimum at perhaps A.D. 950. On the other hand, one of Landscheidt's most important (threshold) solar events, the Medieval Maximum, is dated to A.D. 1128 (this of course coincides nicely with spectacular drought events in the American Southwest). Perhaps,

as a working hypothesis, we can agree that this solar event definitively kicked off the final mode but that the extreme oscillations that are its signature were prefigured during the last couple of centuries of the Stable Optimum. This would be a classic metastable equilibrium model for the complex atmospheric-ocean dynamics of a climate mode shift.

Mode 7 (ca. A.D. 1100 to 1550): High Unpredictability

The turmoil into which unsettled weather and plague plunged Europe is well documented (Hughes and Diaz 1994; Lamb 1982:162–200). Mode 7 covered most of the so-called Medieval Warm period (ca. A.D. 1290–1522). In many places, it was marked by moderate to severe oscillations in climate before the relative stability of the Little Ice Age (ca. A.D. 1550–1840 [or 1910]). Other parts of the lowland tropics underwent significant dry periods (Maloney 1992), and Meggers (1994) claims that this mode began, ended, and was interrupted midway by what she labels mega–El Niño events. In the American Southwest, a significant drought from A.D. 1130 to 1180 anticipated Dean's period of high spatial reversal from around A.D. 1250 to 1450 (1996:46; see also this volume). The various ice cores show the period from A.D. 950 to around 1530 to have been one of episodic warming (with a maximum from 1313 to 1344). Elsewhere in Africa, the record also is one of abrupt climate shifts (Hassan 1996).

Various geoarchaeological projects in the dry, northern regions of Mande country show this to have been a period of intermittent severe droughts interrupted by periods of improving precipitation. Some formerly fertile regions, such as the Méma, were no longer inhabited by any significant sedentary populations by the end of this period. Overall, West African lakes were fluctuating at a low mark. Lake Bosumtwi began to recover in around A.D. 1300. Rainfall stabilized at a level of more than 20 percent (relative to the 1930–1960 standard) only in the sixteenth century (maintaining that level until the eighteenth). The higher West African rainfall that corresponded to the European Little Ice Age was also somewhat more stable than during this High Unpredictability mode, although greater humidity must have brought new waves of plague and debilitating malaria (Cissoko 1968). Still, with new sources of historical documentation, we can begin to date droughts with a precision heretofore impossible (1640–1644; the 1670s and 1680s; 1738–1756; the 1770s and 1790s; and 1820–the early 1840s; Nicholson 1976, 1980). A humid phase began in the late 1860s and continued to 1895–1898, only shifting to a drier period in the late 1910s. We now have the quality of evidence that allows closer comparisons with the instrumental data of the twentieth century, allowing scholars such as S. Nicholson to compare present-century "anomaly types" to recent (nineteenth century) historical climates (1994:127–129, fig. 9).

Thus stands our understanding of the climate change variables, at various timescales, that have affected the Mande peoples improves continuously. But these facts of objective climate change are just one side of the equation

describing how the Mande *perceive* climate change and how they confront that change in the world of community-warranted action. The other side of the equation is social memory. To understand the evolution of Mande social memory, the discussion must shift to authority and decision making.

The Mande Weather Machine

The Mande weather machine is all about fundamental notions of authority. Such notions go to the root of the Mande philosophy of causation—what I consider to be the core of their social memory—and of their structural transformations back into deep time. Although the development of Mande archaeology is today at the stage that Mayan archaeology found itself in perhaps 1900, I begin my discussion here with the expectation that we will eventually find material imprints going back to the Late Stone Age of the earliest expressions of power and place. McNaughton (1991, 1992) and Vansina (1989) make the classic argument for allowing symbols and legends to tell their history of deep-time processes.

A confirmatory function of dirt archaeology directed toward power and symbols is necessary not just to give dates and an environmental context but more fundamentally to lift the veils of subsequent episodes of editing from the core version of oral tradition. A classic example of this cumulative editing is the story of the northern Mande (Soninké) culture hero Dinga. As the archetypal Stone Age hunter, Dinga makes a knowledge quest to and then from Yemen or, in a classic appropriation of the earlier hero tale by later Muslim dynasts (Dieterlen and Sylla 1992:6, 48 passim), even Mecca. On his travels he is accompanied by members of the blacksmith caste, even though iron has not yet been invented (52) (everyone, smiths included, gets in on the reinvention act). Dinga sires Bida, the snake whose death by an act of social treason brings seven years of drought, outmigration, and social collapse to the Soninké. The Bida story tells not simply a fact of the fall of the Ghana Empire but preserves a memory of millennia of catastrophically low precipitation.

The confirmatory archaeology will never of course touch on every aspect of these traditions. But the material record of subsequent transformations, inventions, and appropriations will be the very stuff of historicity. Historicity—not just attaching a date but identifying the social value attached to a symbol or action in deep time—remains the central problem for the historian of the overgenerous Mande corpus of traditions. The second difficulty arising when writing a history of Mande social memory is the high value placed on secrecy. Power comes from garnering and secreting knowledge away (McNaughton 1988:14, 41). According to Conrad's description of Mande oral art, "most of what they are saying is left unsaid, and much of the rest is couched in symbolic language" (1995c:21). The scholarly dissemination of knowledge, to the Mande view of power, is sheer madness. Hence there are certain aspects of Mande authority, certain nuances of *nyama* (vital force), and certainly certain sacred places about which we will never learn.

Can we go beyond these indictments of the very sources we must use to uncover the role of social memory in the long-term Mande responses to environmental change and abrupt stress? I suggest that the climate mode shifts outlined above were elements of large ecosocial crises that shaped core values and subsequent transformations of authority. Such large-scale mode shifts superimpose themselves over periodic, if not cyclical, stress episodes at the interannual scale that probably have always characterized the lowland tropical semiarid Mande lands.

Changing climate will be only an element—sometimes greater, sometimes lesser—in periods of significantly changing circumstances in the objective relations of people with their neighbors or their environment. It is through a succession of crises that dynamism is injected into the evolving notion of authority of Mande. Because oral traditions, myths, and material symbols are the means of communication of these notions of authority, they have preserved a long social memory of appropriate action and keys to know who may initiate action.

In developing the concept of social memory of climate change in Mande, however, it would be quite wrongheaded to see crises exclusively in terms of climatic stress or political turmoil. The periods of crisis defined above are just too long and, more importantly, too complex. It is best to think of Mande crises as periods of changing circumstances that could lead as easily to opportunities and cultural elaboration as to collapse of cultural systems. Middle Niger urbanism emerged during the Stable Optimum crisis of the first millennium A.D. Specialization and early complex society may have emerged during the Fluid Frontier crisis of the last millennium B.C.

From crisis to crisis, certain core values were symbolically reaffirmed, appropriated, manipulated, and reinvented by Mande Men and Women of Crisis. These Mande heroes (and the critically important women whose instruments they were [Conrad 1995c]) move through and themselves create enormous packages of occult power by transforming the sacred landscape. As they harvest power from the dangerous symbolic landscape, they acquire the authority and knowledge to deal with climate change and social change. Indeed, as weather machines, they can themselves initiate weather events.

"Men of Crisis" is a deeply entrenched Mande concept that arguably goes back to their genesis in the Late Stone Age. It may have emerged initially with hunters, who were very probably the first specialist holders of occult and social authority (Cissé 1964:190). A new wave of interpretation of the Mande epics is concerned not just with historicity but with *kuma koro* (ancient speech revealing the deepest notions of power [Conrad 1995c:1, and pers. comm. 1996]). The "ancient speech" view of authority leads to a belief that from very ancient times Men of Crisis traveled to sanctified places, places already highly powerful and dangerous because of their natural bizarreness (physical essence) or because of the presence of spirits. Such spirit inhabitants could be avatars from the realm of *faaro* (earth or water

spirits) or even godhead manifestations with primary responsibility for earth-level creative processes, such as the Bida serpent (Conrad, pers. comm. 1996). Mande heroes visit these places to harvest power. In earliest, hunter times (in the Late Stone Age?) the harvest took place by acts that sometimes involved killing the guardian snake, crocodile, buffalo, or spirit in human form. As I will discuss, the nature of that act, and hence Mande political process, is transformed by smiths and later by secular dynasts. With each transformation, control over weather (which is, after all, just one aspect of the life force) is also radically reconceived and indeed augmented.

Here I will concentrate on the social sanctions (social memory) that enable the Men of Crisis to respond to the climatic dynamism embedded in the crises through which they live. They also are the central actors in the early Mande drama of resistance to centralization (S. McIntosh 1999; McNaughton 1991, 1992). The symbolic and mythic repertoire relating to environmental stress and (nonsymbiotic) ecological relations of neighbors is intimately tied to the success of that resistance (McIntosh 1993a, 1998a, n.d.). The persistence of that resistance to hierarchy and the enduring appeal of heterarchy as a flexible response to climate and political stress and change (see Crumley 1994a:12–13, 1995) is explained by looking at those who were sanctioned to transform symbols to express new forms of authority during periodic crises. These were the same people sanctioned to pass with impunity across a danger-charged landscape in order to harvest benign occult power for their community.

The admitted infancy of the archaeology of the first crisis I discuss in this paper (mode 4, Fluid Frontiers: 3000 to 300 B.C.) sees the first expression of recognizable Mande notions of authority and hence the play of social memory. In 3000 B.C. or perhaps even in 1000 B.C., there probably was not yet a reasonably coherent group speaking related languages covering the vast territory that came to be called Greater Mande, thus there is no proto-Mande cultural template. Perhaps the earliest expressions of the Mande social memory emerged first in the northern (later Soninké) regions, where the climatic stress component of the first crisis would undeniably have been most severe.

In any event, I suggest that Mande notions of authority were pioneered by Late Stone Age hunters and were communicated over a vast area by the mechanism of their closed-membership, secret corporations (*Donso tonw* or *kana lemme*). These secret societies preserved the foundational traditions of how humans may tap the power of the earth's nyama and how humans may navigate over a symbol-charged, perilous landscape, and curated myths that may be the first expression of that landscape as a power grid with highly charged nodes (Mande onomasticon) (McIntosh 1993b).

Hunter-Pioneers (Fluid Frontiers Mode)

We know little of the Late Stone Age archaeology of the southern Mande, the so-called Mande heartland (see MacDonald 1994:157–226, 1997). In the

north, in present-day Soninké country and further north into the desert, communities would have been intensely aware of the crisis of significant climatic oscillations and overall decline from stable pluvial (high lake) conditions to marginality. That crisis played out along the banks of shallow lakes and in the interdunes and paleochannels of the southern Sahara and Sahel, particularly in the Mauritanian Hodh and Mali's Azawad and Méma (MacDonald 1994; McIntosh 1994:167–173; McIntosh and McIntosh 1983:229–240, 1988:97–102).

Future research must confirm or deny the hypothesis that Fluid Frontier period southern Saharan societies changed across several dimensions. Shifts in plant exploitation would eventually lead to the local domestication of sorghum, millet, rice (*Oryza glaberrima*), and minor grains such as fonio. Intrusive (specialized?) pastoralism became an entrenched way of life for some communities. Patterns of population density shifted, with some favored locales (Tichitt cliffs, seasonally flowing or still-ponded paleochannels, and the hundreds of interdunal depressions) becoming quite populated and their residents relatively more sedentary than ever before. Other, less favored regions saw increasingly ephemeral occupation. Some communities made great treks in search of more welcoming land, often coming into conflict with autochthonous communities (MacDonald 1997).

More speculatively, most resource exploitation became intensively seasonal, but some sites show evidence of intensive specialist exploitation. By the end, in regions such as the Méma, specialists appear to have gravitated together for exchange and seasonally lived next to one another in segmented but articulated communities (McIntosh 1993a; Togola 1993:38–64; MacDonald 1994). Who decided when the community should pick up and move and to where? Who kept the peace between increasingly specialized (alienated) components of the community? Who regulated relations between different communities (sometimes senior and junior in terms of duration of presence) with competing conceptions of the shared landscape? The Fluid Frontier mode potentially represented a severe and novel crisis of authority.

Nothing in the archaeology reveals who would have had the authority to maintain peace in an increasingly segmented yet articulated landscape or who would have led the migrations when the desert finally prevailed. The oral sources concur that hunters formed the first secret societies that crosscut kin and local territorial loyalties, for the purpose of acting as guardians of social equilibrium, keeping the peace between community segments and neighbors, and making exploration (or "knowledge") journeys across unknown territory (Baa and Sunbunu 1987; Cashion 1984:13, 81, 102–115, 310–316; Cissé 1964:175–179, 186, 194–204; McNaughton 1988:10).

The first hunters' societies were ancestral to the occult secret societies and power associations that historically have defined so much of the Mande political and spiritual world (Brooks 1993:39–46; Conrad and Frank 1995). To what extent were ancient hunters' associations also the *nyamakalaw*, the artisan and specialists' corporations that define much of Mande social and polit-

ical space? What were the sources of the hunters' novel authority, that is, their ability to persuade the community to act on their privileged vision of causation in the world? Why was their corporation invested as the repository of cumulative knowledge?

Hunters dealt in vast quantities of nyama. In fact, it was during this crisis that they probably pioneered the very concept of nyama that is the shared heritage of the many Mande subgroups to this day. Nyama has been defined by many in subtly different, all complementary ways. It is one of those portmanteau cultural concepts that defies precise, abbreviated definition in any Western language. Undoubtedly even today many nuances are among the most jealously guarded secrets of nyama practitioners, the nyamakalaw, such as members of the *Komo*, *Poro*, or *Sima* power associations. Nyama is the malign if improperly controlled energy that flows through all animate and inanimate things (Brett-Smith 1994:38). It is the energy of action released by any act (Bird 1974:vii–ix; Bird and Kendall 1980:16–17). It is the flux or flow of any object or living being's soul that executes the soul's will (Cissé 1964:192–193). My personal favorite is McNaughton's equation of nyama with occult energy as the source of moral reciprocity (human to human and human to all earth forces, including climate) (1988:16, see 15–21). For McNaughton, it cannot be created, only augmented, and nyama "is a little like electricity unconstrained by insulated wires but rather set neatly into a vast matrix of deeply interfaced social and natural laws" (16; see also Dieterlen and Cissé 1972).

In terms of the Mande perception of climate change, droughts appear, the environment changes, and weather springs its unpleasant surprises not because of physical laws of nature but because of perturbations in the flow and nature of nyama within the landscape. To be an active Mande human is to search to understand (curate knowledge) and to control (act on) the flow of nyama. The curated understanding of how nyama perturbations affect the environment (writ large) is a physical model of causal explanation. This model of causation allows the Mande hero (and his society) to predict the effects of action on any of those components. But the Mande weather machine would break down completely without supplementary components that warrant moral authority. Who has the authority to manipulate these dangerous forces that can bring on drought or summon the rains or kill at long distance merely with a thought?

How one controls nyama (*kala*: becomes the "handle" of this dangerous life force) and the rules for action that augment nyama tangibly changes through time. This is the story of the emergence of new authority groups (nyamakalaw, especially smiths, and later the secular dynasts of the great second millennium A.D. empires). This is also the story of how the hunters were eclipsed (or shunted to a more restricted domain of social authority). For David Conrad, the kuma koro is thus all about the emergence of new groups, their battles for authority, and the resolutions of those contests, which involve the invention of new traditions within the context of ancient

notions of sacrality and authority. All this went on as the Mande were vitally, desperately interested in climate and unswervingly convinced that the best and brightest among them can do something about it.

In the first crisis of Fluid Frontiers, the role of the hunters was legitimated by their (unique?) control of the dangerous life energies of their animal prey (and killed human enemies). The role of the hunters was not just to provide their village with meat and protection from external human enemies. Their primary role was to explore the rapidly shifting physical and occult landscape and to acquire and curate that occult power. Extraction of nyama was the source of the hunters' moral authority. It was the basis for their powers of persuasion to maintain social equilibrium, the authority for their use (as a corporation) of consensual force against witches and vampires (such as the soul-sucking living dead, *xon-faaf* among the Serer) who were major causes of droughts [I. Thiaw, pers. comm., 1996]). With this authority, hunters deal with the uncontrollably violent members of the community.

At this stage, hunters extract nyama by controlling the life energy let loose at the death of their prey. There is an especially courageous class of aquatic hunters of hippopotamus, water python, crocodile, and massive harpoonable fish such as *Lates niloticus*. The death of any living being is as potent a perturbation in the power landscape as is any feared natural phenomenon, such as dust devils (known as "les sorcières"), or energy-laden mountains, or spirit-infested bodies of water (see below). Hunters' societies find the appropriate means to curate that nyama through energy cells. Hunters proudly sport these energy cells in the form of the hunt paraphernalia and trophies recognized as the most ancient of the hunters' symbols: bow and quiver (Cashion 1984:177–178), ground stone ax (172; Dieterlen and Cissé 1972:39), spear and harpoon (Baa and Sunbunu 1987:99; Cashion 1984:176–177), poison and secret power-filled horn (Cashion 1984:147–148; Dieterlen 1957:134), and the various dried heads (especially snake and monkey) hung as gris-gris all over the hunter's invisibility-making smock and bonnet. These are the sumptuary items and symbols to be appropriated and transformed by other groups during subsequent crises. For example, Fakoli, the archetypal smith-sorcerer, makes quests to acquire the medicine items hung from his sorcerer's bonnet (including birds', cats', and snakes' heads) (Conrad 1995b:13–14, 1992).

Fakoli's quest is the second source of Mande authority, the knowledge journey, or *dalimasigi*. Navigation of a sacred or symbolic landscape is not unique to the Mande; the Maya *sacbeob* roadway replicated sacred pathways crisscrossing a cosmological or spiritual landscape, and the North American Hopewell may have had similar spirit paths or "white roads" along which pilgrims traveled for blessings from other communities and from communities of the dead (Lepper 1995). In the study of the epics, it is increasingly difficult to disassociate the concept of nyama (or of *sabu*, female power to set a brother, son, or husband on the path to achievement) from the idea of "charismatic figures moving through a dangerous symbolic landscape harvesting power, authority, and knowledge" (Conrad 1995c:2).

Early expressions of this concept are illustrated by the lives of two culture heroes, Dinga of the Soninké and Fanta Maa of the Bozo (Soninké-speaking aquatic hunters and fisherfolk). The latter, still in his infancy when he learns how to control the nyama unleashed by killing animals, becomes a promiscuous hunter. Fanta Maa's story (Baa and Sunbunu 1987) mostly concerns how, under threat of extinction, the animals come together and elect a gazelle to transform into a young woman in order to seduce Fanta Maa into the wilderness to his death. Fanta Maa (and his sabu mother, who bore him of the genie of Joron-Kula, one of the most sacred locales) uses the hunters' paraphernalia to undo the plot.

In the process, the hunter Fanta Maa is led to many places of magical conflict and dangerous nyama. At each, he finds and gathers new bits of knowledge about how to manipulate the local nyama. At each, he finds new symbols or potions for his horns and jars. At twelve such locations, he marks his trail (for subsequent occupation by migratory Bozo) with altar jars, fetishes that serve to hold powders and act as oracles. All stages on the quest are dangerous. For example, at Nanun, upstream of Jenné, the guardian crocodile Bama-Ngala-Nyama (known as the "ravisseur des âmes jeunes") has already slaughtered one hundred less skillful hunters. When Fanta Maa finds the magic that allows him to take as trophies the head and gold-filled tail of Bama-Ngala-Nyama, he liberates one of four most propitious territories (curiously called "brousse lointaine") for Bozo settlement and perpetual hunting. The four impenetrable territories he eventually liberates are Nanun, the Faya plain near Bamako, the swamps (Pondori?) near Jenné, and Yaasàngo near Dia in the Masina) (Baa and Sunbunu 1987:79–105). This fits nicely with the archaeological evidence that some of these regions were first opened for colonization by sedentary populations at the end of the Fluid Frontier or beginning of the Big Dry period.

In Mande tradition, killing the crocodile also gives one access to the most powerful poisons, an added bonus for Fanta Maa. Because of this and similar adventures during his dalimasigi, Fanta Maa is attributed with the discovery of *korté* (the sorcerer's recipe for harnessing nyama in powdered form that allows one to kill at a distance) and he seeds the Bani tributary of the Niger and the important (later, iron-producing) Benedougou region southeast of the Middle Niger floodplain with occult power.

Fanta Maa is clearly no slouch. You would not want to meet his pirogue on a dark distributary. But Dinga, as grandfather of the Ghana kingdom, is regarded as an even more awesome hunter. His stories too are about his movements, the power places where he prevails over (and kills) the guardian animals, and the various knowledge animals (birds, hyena, vultures) that show him how to dominate local spirits in order to deposit his ground stone ax and korté-filled oracle altar jars (Dieterlen and Sylla 1992).

The accumulated nyama of Dinga is genetically passed on to his son, the beneficent godhead and monstrous water snake Bida (and twin of the Ghana founder, Diabé), into whose jealous care the climatic well-being of northern Mande is entrusted. Bida is the classic case of spirit animal as Mande weather

machine. In his travels, Dinga the ancestor of the hegemonic Soninké and founder of their hunter society often encounters members of even older, autochthonous hunter corporations (*kana lemme* [Dieterlen and Sylla 1992:68–71]), whom he vanquishes or to whom he gives wide berth, depending on their relative command of the power landscape.

The common theme of the earliest expressions of dalimasigi is the voluntary removal to the wilderness (where nyama runs rampant and chaotic [McNaughton 1988:16–18, 148]). Danger is everywhere. This is not an exile for community transgressions; it is for the good of the stressed community that the hunter makes this dangerous tour of powerful locations. There he kills the proprietary spirit animals taking the form most frequently of buffalo (Bulman 1989:179), hyena, crocodile, or snakes (Bathily 1989:79). Killing the guardian animal liberates vast masses of nyama that only the most able hunter can control, and frees well-watered lands for hunter-led migration. The snake may be secretly followed to water by the hunter. The snake may even succor the famished hunter with milk from its tail (Kesteloot, Barbey, and Ndongo 1985, where this also figures in non-Mande Fulani migration myths). The snake may even willingly guide the hunter, an important precursor to how the smiths appropriate the nyama of the serpent during the next period (Cashion 1984:172, 237; Cissé 1964:187; Conrad and Fischer 1983:61–67; McNaughton 1988:17). But later the snake is almost always killed to unlock its superabundant nyama, and its head and skin become honored trophies (fig. 5.6).

During the Fluid Frontier climate mode, then, the hunter plays a critical role in defining how acts extracting power (nyama) and journeys to accumulate occult knowledge (dalimasigi) actively create the fluid sacred landscape. Here, a long-standing concern of Mandeists coincides with a growing concern of prehistoric archaeologists generally (Carmichael et al. 1994), namely, how secret-sacred places are sanctified as such (or how heroes are elevated by visiting them) and how their designation or relative power changes as the political landscape changes. This class of questions about the power of place is asked, for example, when Mandeists question where Sunjata died (or transformed himself into an immortal hippo) (Bulman 1989:176) or whether Kangaba's sacrality is an invented artifact of the Mande heartland politics at the birth of the Mali Empire or metamorphosed out of a far older sacred landscape (Conrad 1994:358). Other traditions state that Kangaba is only centuries old, a place perhaps invented to keep nosy outsiders from the original sacred site safely entombed in Mande canons of secrecy.

The Mande mapping of the power of place goes beyond a simple two-dimensional map of power localities, however. For Greater Mande, we can talk about an evolving notion of authority expressed as a spatial blueprint of the covenantal assimilation of power. Mande itself is a grid in space, the nodes of which describe a vertical axis of sacrality and of vital information about the viability of various geomorphological features under different climatic conditions. In this sense, the study of Mande social memory most closely approximates the biblical study of onomasticon.

Figure 5.6. Mande hunter and snake avatar.

In biblical exegesis, onomasticon can simply be a listing of contemporaneous sites mentioned in the Bible or ancillary sources. Increasingly, however, onomasticon has come to mean the study of power localities as mnemonics of deep-time memory of the relative power of households or lineages associated with those places (Matthews and Benjamin 1993; Wilson 1977). So here the term *Mande onomasticon* will describe the study of Mande as a network of power localities. (There may be a proper Mande term for this conception of social memory, but it may be too secret ever to have been leaked out to scholars.) The critical issue is the three-way connection among Mande onomasticon, social memory of past climate change, and the community-recognized range of adaptive responses. This issue has not previously been the concern of scholars looking at the network of Mande sacred places, so the following remarks will be somewhat sketchy.

Many of what may well prove to have been the oldest of the sacred places, the most venerable Soninké hunter lodges (*Xaso*), are in fact revered as reservoirs of curated knowledge about resources within an extensive catchment. Even master hunters will take pilgrimages to those lodges to

accumulate more (and increasingly arcane) knowledge. When Dinga, for example, vanquishes the spirit animal or genie of high-power localities (such as Tourougoumbé or Dalangoumbé [Dieterlen and Sylla 1992:49–50]), he founds a cult to tend the knowledge about the local environment acquired from these genies' rival cults and accumulated by the autochthonous inhabitants. This is knowledge (and authority to act on that knowledge) widely disseminated to any initiated hunter (in keeping with Mande rules of secret, privileged information). These cult locations become stations on dalimasigi down through the centuries.

Fetishes (groundstone objects, water-filled altar jars, powders) from Dalangoumbé are deposited in each altar (cult center) Dinga establishes subsequently. The active hero seeds the Mande onomasticon. Some secret-sacred places become associated with mountains (and caves) and others are situated on or next to water (such as the hundred Faro cult locations on the Niger and its Middle Niger distributaries, or the dense network of water-spirit cults in the Guimbala dune and distributary land downstream of Lake Débo [Gibbal 1988]). Is this the origin of the particularly intensive power ascribed to mountains or hills fronting or surrounded by water (such as the Kouroula hills of Kri along the Niger, the Koulikoro hills where Sunjata disappears at his death, or the Gourao and Soroba hill at Lake Débo [Dieterlen and Sylla 1992:91–92, map 4])?

One aspect of the earliest Mande onomasticon has particularly exciting possibilities for understanding southern Saharan populations' response to the final desiccation of the desert. On purely archaeological and ecological grounds, one would expect the north-south–trending paleochannels of the Sahara and Sahel to be natural reservoirs of climate-distressed populations, the locations for their experiments with new domesticates and new occupation specializations, and (ultimately) corridors for their migratory pulses north and south with cycles of desiccation and temporarily better precipitation (McIntosh 1993a). And indeed the traditions about the Mande perception of sacred space, in addition to mentioning discrete points, talk in detail about a fluid network of underground watercourses that link together the most sacred places or even genie-inhabited trees with, especially, the Niger River (Brett-Smith 1994:129, fig. 23). At one level, this functions as a map of safe passage across a severe drought landscape because paleochannels are intermittently ponded where the topography dips below the level of the water table.

Mande onomasticon as a predictor of human occupation and climate response can, however, show curious twists of evidence. In the Ghana tradition of Koumbi, the snake Bida lives in an aquatic underground quarter of the town (Mallaara)(Dieterlen and Sylla 1992:55–57). The lair of this ultimate weather machine (Bida) is linked by a subterranean stream to another subterranean channel from Lake Faguibine (Lakes Region) to Nioro, around 220 kilometers (around 130 miles) to the southwest. These subterranean channels are further linked to the Vallée du Serpent paleochannel north and west of the Méma that I have hypothesized would have been a natural corridor for third through first millennia B.C. migrations (McIntosh 1993a:203).

MacDonald's recent survey of the Vallée du Serpent yielded the completely unexpected results of scores of mid-Holocene macrolithic sites (7000–4000 B.C.) and many very recent iron and tobacco pipe-yielding occurrences (perhaps dating as late as the nineteenth-century Tukulor incursion from the Middle Senegal), and virtually nothing between (MacDonald and Allsworth-Jones 1994:76–77). In a Sahelian archaeological landscape otherwise dense with Late Stone Age sites of the Fluid Frontiers time frame, some powerful force prohibited occupation of an otherwise privileged paleochannel environment. A Mandeist might be forgiven for wondering if perhaps the fear of a traveling Bida overcame the desire for an inviting habitat!

It is little surprise, then, that at the beginning of the last century the militant jihad of Sékou Amadou—who was intent on imposing a strict Islamic theocracy on the Middle Niger—had as a major goal the elimination of these venerable sacred places (Brown 1969; Gibbal 1988:38). Sékou Amadou purposefully removed communities from these power locations as part of his larger scheme to rewrite history and refashion the landscape. In this, however, his caliphate was an anomaly in the succession of authority in Mande. Most who emerged (or who came into prominence) during successive climate modes saw more to be gained by the appropriation and reinvention—that is, the preservation with transformation—of the core of Mande social memory.

Preservation with Transformation of Mande Social Memory

Hunters may not have been the only corporate occupation group to appear by the middle of the first millennium B.C. Future archaeology will have to inform us whether iron craftsmen and perhaps also leather workers and griots (keepers of oral history) appear as members of self-defined corporate groups centuries before the onset of the next crisis at around 300 B.C. From evidence at sites such as Jenné-jeno, smiths came into their own at least by the first centuries A.D. At some point, they invented a radical transformation to the basic conception of nyama, or so they are credited in the oral traditions. The Big Dry (mode 5, around 300 B.C. to A.D. 300) was a long, severe dry period in which southern Saharan populations suffered terribly. On the other hand, the rich alluvial environments of the Middle Niger and the Middle Senegal apparently first became available for permanent occupation at this time (McIntosh, McIntosh, and H. Bocoum 1992; McIntosh 1995). Was this the time that Fanta Maa seeded the swamp wildernesses? Communities such as Dia and Jenné grew explosively. Now the crisis of authority was: Who claims new territory? Who says to the rest of the community, "We pick up now, and we settle there"? Who negotiates for land and water rights with the autochthones?

The full details of transformations to authority are beyond the scope of this chapter (see McIntosh 1993b, 1998a:187–189). Briefly, smiths take the

extractive notion of nyama of the hunters (power released by the act of killing) and turn it into a transformative concept. Nyama is made even more powerful, indeed qualitatively more so, by transforming earth and fire into a new substance (iron), raw wood (or other materials) into ritual power packages (*boli*) or masks, and wild guardian animals into guarded familiars. The last is especially pertinent. The guardian animals (especially snakes), which before were the avatars of weather and critical environments, are no longer killed to extract their nyama. Instead, smiths hide them away in the huts maintained by their secret power associations (particularly Komo). The transformed relationship of human to avatar is publicly expressed by the ability of smiths to carve the images of animals for use in social-policing dances, rituals, and emergency interventions at times of social or ecological distress (McNaughton 1988:130–136 and 1991:41, 47). These masks "articulate the nature of the world from its occult underbelly" (McNaughton 1991:50).

The smith and his secret associations have begun the process of refining occult-sanctioned persuasion, the resistance to vertical, coercive power that will mature in the proliferation of corporations during the climatic optimum of the first millennium A.D. (R. McIntosh 1999; McIntosh 1984). Each corporation will have its own domain of authority. Society becomes horizontally complex. Mande heterarchy is based on the complementarity of competing power associations acting as overlapping agencies of cooperation and competition (S. McIntosh 1999). Like the hunters before them, smiths (and Komo or Poro leaders particularly) take charge of the social values of stability, cohesiveness, and spiritual balance in society. In fact, Conrad (pers. comm., 1996) wonders whether the seven smith-led master Komo lodges correspond to the seven *mansaduguw*, or pre-Mali polities, of the Old Mande heartland. But smiths are just the most visible of several competing power associations that harness energy effectively to resist power asymmetries.

The Mande had found a solution to the problem of how to accommodate the inevitable alienation of complexity while maintaining a kind of heterarchy that provided flexible, responsive adaptations to a mosaic and changing environment (McIntosh 1993a). Smiths appropriate dalimasigi just as effectively. In the most obvious case, the infant Fakoli (the archetypal smith) takes a pilgrimage to the most vital sacred places of Mande, with his foster mother as guide (Conrad 1995b:9–13). At each place, he treads sacred ground and bathes in medicine (altar?) jars, accumulating ever-greater amounts of knowledge and nyama. In a bizarre variation, Sumaworo, the smith-king of Soso and great antagonist of Sunjata, takes his dalimasigi as a fetus, shifting among the wombs of three sisters (Conrad, pers. comm., 1995).

There is a large literature about what McNaughton (1988, 1991, 1992) calls "entrepreneurship": the obligation on *komotigi* (Komo leaders) and apprentice smiths to travel from one sacred power location or one master forge to another in order to accumulate technical and occult knowledge as well as to obtain ever more powerful boli (Conrad 1992:154–155; Dieterlen 1957:134). And there is a new suite of sacred places, additions to the Mande onomasticon, associated with smiths. One example is Kolokanté, where an

early master smith, Kassime Koné, buries the canoe that took him on the dalimasigi by which he built up knowledge of this new craft.

For the purposes of this paper, the most important thing about this shift from extractive to transformative authority is the attendant change in the conception of the Mande weather machine. No longer is the hero simply an extractor. Now the Mande smith, the transformer, is a weather *maker*. Later he will vie with the Islamic marabout or Islamized dynast for recognition as the one to control most successfully the nyama of the sky, the causative energy of the monsoonal atmospheric circulation system (McNaughton 1988:50–51). There is some hint in the Dinga story that the water-filled altar jars may have had some role in rather inchoate rainmaking rituals (Bathily 1989:48; Conrad and Fischer 1983:63). Now the power to *make* weather is fully expressed as one of the occult craft skills that sets smiths apart from hunters, griots, and the like (Dieterlen 1957:127–128; Herbert 1993:110). In most traditions and ethnographic situations, the snake familiar is attributed with powers to bring rain. It can be made to do the smith's bidding once it is bundled in a secret place by its smith guardian. Perhaps it is not surprising that some of the earliest archaeologically attested rainmaking paraphernalia appear associated with a Jenné-jeno smith's atelier of the A.D. twelfth century (McIntosh 1993b; McIntosh 1995:39–40, 49).

The next crisis is one of prosperity and urbanism. The Stable Optimum (mode 6, A.D. 300 to around 1100; generally long climate improvement and low oscillations) was a time of growing prosperity and craft production. West Africa, and particularly the Mande Middle Niger, was integrated by a sophisticated commercial network onto which the more famous trans-Saharan luxury and slave trade was grafted by the turn of the millennium (McIntosh 1994:173–186, 1995:360–361; R. McIntosh and S. McIntosh 1988: 149–153; S. McIntosh and R. McIntosh 1988:110–125). In places, this was accompanied by higher populations and large cities. The trend toward horizontal complexity (heterarchy) accelerates. Prehistorians speak increasingly of a political landscape of "overkingdoms," areally extensive confederations without vertical control structures. In some cases, these were nominally headed by smiths or their associations (Bathily 1989:66, 79–86, 158–162; Bocoum 1990:159–172; McIntosh 1995:396–398). Conrad (1995c:21) comes right out with the assertion that the old Mande *mansaduguw* (overkingdoms) were metal-producing polities under the control of smiths.

The stable first millennium A.D. most likely witnessed the elaboration of themes of Mande authority set during the Big Dry. McNaughton's long-distance smith networks expanded. So too did the numbers and hierarchy of Komo centers (including the emergence of the seven master centers, the names of which are among the most jealously guarded secrets even today). I do not necessarily detect a shift or reinvention in Mande concepts of weather control during this period. Rather, there is an elaboration of the resistance-to-centralized-control and heterarchy-encouraging mechanisms throughout the millennium.

As remarkable as this long history of resistance to centralization is, the

early second millennium brought the first signs that the absolutely dangerous power of nyama could also corrupt absolutely. New charismatic individuals try to subvert traditions of horizontal authority (e.g., the Sumaworo figure, metaphoric or real, the smith gone bad). Perhaps partially in response to the stress of early cycles of climate oscillation beginning as early as A.D. 900, elites do appear by the end of this period in the form of those well-appointed interments in massive funerary tumuli reported by al-Bakri for Ghana (Levtzion 1973:25–26) and investigated in the Middle Niger Lakes Region (Desplagnes 1951) and the Senegambia (McIntosh and McIntosh 1993). By the end of this period, West Africa suffers the earliest warrior states, the precursors of the "aristocracy of terror" (Bathily 1989:232) that used cavalry and slaving to expand Mande control during the next phase (Brooks 1993). This, then, would be the birthing time of the famous *kèlèmansaw*, the warlords of the Old Mande epics (Conrad 1995c:2, 28).

The final climate mode-shift period (mode 6, Unpredictability, ca. A.D. 1100–1550) corresponds to a transfer of many aspects of older authority to new secular dynasts. Some are represented as despots (Sumaworo), and some as heroes (Mali's Sunjata and Fakoli, the Tunkara of Méma). Now, Mande society must also contend with an alien ideology and source of new symbols for the symbolic reservoir: Islam. The epics relating this redefinition of authority are truly supra-Homeric in scope. An army of Mandeists returns each year from Guinea, Mali, the Côte d'Ivoire, and so on, with ever new versions and vastly expanded details.

It is important to note here that analyses of these events have not taken account of the massive climate shifts. Brooks's important treatment (1993) of expanding Mande polities, commerce, and entrepreneurial diaspora acknowledges subcontinental shifts of rainfall isohyets but at too gross a scale. No scholar yet has dealt with the fact that the great empire of Mali rose at a time of massive depopulation in the Mande granary of the upper Middle Niger. Demographic catastrophe also besieged the Middle Senegal Valley, heartland of the Takrur Empire. We have to discard older commercial explanations (stimulation by the Arab Saharan trade) or demographic interpretations (Niger and Senegal valleys as "virtually human anthills" [Niane 1984:156]) for the development of these empires.

In terms of the analysis here, the new secular dynasts reinvented the authority of smiths (and griots and other *nyamakalaw*). Conrad assesses the dalimasigi of Sunjata, in the course of which he systematically breaks the tabus of each power location: "Fakoli's [the smith's] progress through the sacred sites of Mande is an exercise in passive acceptance of the powers bestowed upon him, and a reaffirmation of ancient cultural values. Sunjata's journey is a study in contrast, characterized as it is by aggression and the systematic violation of the *tana* (taboo) of each of the old Mande chiefdoms" (1995c:17). The Islamized dynasts must tap the power of nyama and yet also find ways to transcend the constraints of older canons of heterarchy (McIntosh 1984). In the new parlance of power, blacksmiths become the "slaves" of the new order (Bathily 1989:222–223; Conrad 1992:167–171). The appro-

priation process reaches back even further in symbolic time: To found the Mali empire, Sunjata appropriates the nyama symbols of hunters (bow, quiver and [stone?] ax [Cissé 1964:176; Conrad 1992:176–177]). He also invents elaborate (and fictive) kinship relations with powerful hunter lineages in order to lure the hunters into his shock troops (*totadyo*: "esclave archers," slaves of the sacred cause) (Cissé 1964:175–176, 190; Conrad 1992).

The new dynasts have their own versions of the dalimasigi. Sunjata the cripple-in-exile gains power by visiting (and abusing) power places such as the capital of Méma. In Méma, one of the most powerful rainmaker chiefs befriends him. Fakoli makes a childhood dalimasigi that gives us a virtual map of an older hunters' and smiths' onomasticon (Conrad 1992). The peregrinations of Sunjata's and the later Mali capitals probably is a combined "Imperial dalimasigi" and "Imperial onomasticon" (Conrad 1994): the Mali kings "roam the country seeking zones of power, matching themselves against rival chiefs and occult forces alike" (361). In a classic case of appropriation and reinvention, Sunjata's ally, N'Fagigi, returns from pilgrimage (i.e., dalimasigi) to Mecca with neutralizing boli that he deposits at each of the Middle Niger faaro cult locales (Conrad 1995a, also 1992:152–153, 186). Other returnees from Mecca claim to bring the original smiths' boli and even the very notion of Komo, a very Mande reinvention of history.

Through all these machinations, the new magician dynasts take the art of rain control to a new plane. On the one hand, they tap the power of Islam and of (again) redefined nyama to become augmented weather makers. Additionally, now they control the employment of the smiths' highly dangerous manipulation of weather. Thus, as real-world climate becomes ever more chaotic during the High Unpredictability mode, the Mande found ways to transform their response to climate using venerable canons of social memory.

Society finds ever more powerful ways to influence climate (that is, to influence the occult earth forces and social relations that are perceived to have an influence on objective weather phenomena). At the same time, society preserves venerable mechanisms for understanding climate information (sorting and filtering), for passing on climate experience to approved neighbors and the next generation, and for translating the social perception of climate change into adaptive action. These are canons of social memory that persist to today. T. Togola (pers. comm., 1994, and in this volume) tells of the rapid spread of Islam in rural Malian communities at the beginning of the Sahel drought, in 1968. Islam's spread was part of the peoples' search for influence over that acute environmental crisis. By the late 1980s, however, when the predicted end of the drought appeared not to be happening, there was a rebirth of Komo. The newcomer Islam had to share its place with venerable memory.

Conclusions

Thus, by the middle or end of the first millennium B.C., it is possible to infer the presence, in already recognizable form, of the basic elements of a long-

standing repertoire of hunters' symbols (altar-pot oracles, snake-head trophies, horns filled with dangerous powders, etc.) and legendary figures (buffalo woman, Dinga and Bida, etc.). These symbols and myths form the instruments by which Mande Men of Crisis, those in whom are invested fundamental precepts of authority, act on the world. And the most potent action in these legends always involves wind, rain, and other manifestations of weather. The symbols and myths are instruments by which the community recognizes these people as the holders of authentic knowledge about climate and the rapidly changing environment.

All these symbols and myths are negotiable: soon the hunters' authority will be challenged and elements of their symbolic repertoire will be appropriated, manipulated, and reinvented by members of other corporations (especially smiths). Most importantly, however, the nonnegotiable core values of Mande authority are also in place. The hunters pioneered the bridge linking the unarticulatable core values and occult underbelly of authority with the world of social action. The bridge of social memory was built from the organizing principles of nyama, dalimasigi, and Mande onomasticon. Social memory allowed the community, through the hunters and their secret societies, to sort and filter out climate information (current and remembered), to pass on appropriate responses (especially through the initiation function of the secret power associations), and to act. By the end of the Fluid Frontiers crisis, something recognizable as a Mande weather machine was in place. This earliest Mande social memory structured the human response to perceptions of weather change as produced by that weather machine. And while the core principles of this social memory were preserved through subsequent crises, change is integral.

Mande provides a highly complex cultural model of how climate changes. It is also a very flexible model. For the hunter pioneers, the animal avatars functioned as weather machines outside human society. These animals guarded and sustained critical environments (river, swamp, or wetland) and might, as in the case of Bida, directly bring on or impede rainfall. The role of the hunter was to extract the vast power of this situation (by the act of killing). The hunters' role was also to maintain the correct social relations between or within communities in order to minimize disruption of the climate.

By this reconstruction, the basic structure of Mande social memory was recognizable for some five thousand years. But the conception of the weather machine changed. Out of the extractive hunters' conception grew the active, transformative smiths' concept. A transformed view of nyama allowed privileged humans some active control over rain and over the maintenance of the occult health of critical environments. Animal avatars become secret familiars, allies in this alternative Mande weather machine. And later still a new transformation to the concept of authority (including new dimensions of coercive power and the intrusion of syncretistic Islam) allowed new dynasts to claim even-greater understanding and power of intercession over the climate.

Did this view of the weather machine allow the Mande to understand and mobilize society for effective social action in the face of high interannual variability of precipitation and highly changeable climate? I would argue, emphatically, yes. Does this analysis of the Mande social memory allow historians and archaeologists at least a partial window on Mande motivations and intentionality in deep time? I believe so. The trick is to translate these interpretations derived from oral traditions into hypotheses that can be empirically tested by archaeology.

These deep-time motivations, particles of the very old Mande social construction of reality, are potentially verifiable by archaeologists. Regardless of whether this reconstruction proves correct in all particulars, it is clear that the Mande weather machine is integral to an ancient social construction, or social perception, of the dynamics of the physical environment. Peoples in the past acted on those perceptions. Because nyama, dalimasigi, and the Mande onomasticon are all about the power of place, they should be inscribed on the physical landscape. The multiple transcriptions of the Mande social memory are out there for the archaeologist to learn to read.

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Chapter 6

Memories, Abstractions, and Conceptualization of Ecological Crisis in the Mande World

Téréba Togola

For the last three decades, perhaps no single subject has occupied the attention of scholars acquainted with West Africa more than the desertification of the Sahel. No doubt, most of this interest was stimulated by the stark images of suffering caused by the severe drought that hit the Sahel and savanna belts of intertropical West Africa in the 1970s and 1980s. To understand the origin of this crisis, numerous research projects, including geomorphological and paleohydrological, as well as archaeological, were conceived and carried out in both the Sahara and the Sahel. Some researchers wished to know if the Sahel drought was entirely or principally natural in origin, that is, attributable to natural cycles of climate deterioration and plenty. Others wanted to understand how human activities, such as overgrazing, overfarming, deforestation, or uncontrolled urban growth, contributed to desertification. Undoubtedly, the Sahel drought came at a terribly sensitive time, as the affected nations had achieved independence only within a decade of the first manifestations (1968) and were still unprepared to handle the enormous costs of relief efforts (see Nicholson 1994:129).

We have since come to understand that the Sahel drought is yet another example of millennia of repeated Holocene climate changes in the Sahara and Sahel. Nevertheless, still quite underdeveloped as a research topic is the issue of how societies respond to analogous climate shocks. Questions of how communities have preserved memories of past environmental disasters and perceived situations of crisis have rarely been studied. The purpose of this paper is to attempt to bridge this gap in our knowledge of what the contributors to this volume have called social memory. It is interesting that the peoples of my own country, Mali, while most affected by the Sahel drought are also in possession of a vibrant, living social memory. Most of the data I

present here were obtained from the ethnographic and historic literature and from my own observations in the southern Bambara milieu.

Overview of Late Holocene Climatic Cycles

R. McIntosh (in this volume) gives an overview of recent research on the initiation and persistence of the Sahel drought, research that relies heavily on the superb instrumental precipitation records from Mali. These records go back to the first years of colonial rule (in the last decade of the nineteenth century). Several authors summarize the broad outlines of the climate fluctuations during the Holocene in the West African Sahel and Sahara, among them Petit-Maire (1986), Petit-Maire and Risier (1983), Jacobberger (1988), Nicholson (1976), Brooks (1986), and R. McIntosh (1983, 1991) (see fig. 6.1). Here, I am primarily concerned with the period subsequent to 4500 B.P. and encompassing the first and second millennia A.D.

The centuries following 4500 B.P. were characterized by increasing aridity, increasing oscillations, and the onset of a period of desertification throughout most Saharan and Sahelian localities (Petit-Maire and Risier 1983; Petit-Maire 1986; Jacobberger 1988). The available evidence shows that lakes in many parts of the Sahara, especially in the Taoudenni area of northern Mali, dried up around 4500 B.P., a result of diminishing rainfall. In the forest in Ghana, Lake Bosumtwi declined in level around 3800 B.P. in response to arid conditions (Talbot et al. 1984). Present models generated from Late Stone Age (LSA) studies suggest that this final desiccation of the Saharan grassland brought on significant southward population movements. Smith (1979) reports that around 4000 B.P. the first emigrants from the Sahara were driven by drought toward the wetter granitic massifs of the Adrar des Iforas. Numerous sites attributed to these Saharan populations are found in the Tilemsi Valley, a now-dry river channel running from the Adrar des Iforas to the Niger River near Gao. Further west in the "dead" basins of the Méma, manifestations of the robust "Mechtoid" fisher-hunter-gatherers, who colonized the Malian Sahara, especially the site of Hassi-el-Abiod around 7000 B.P., have been documented at the Late Stone Age site of Kobadi (3300 B.P. to 2400 B.P.) (Raimbault and Dutour 1989). The same process is recorded in southern Mauritania, especially at Dhar Tichitt, where lakes dried up totally around 3000–2900 B.P. (Munson 1976). The presence on the margins of the Méma floodplain of small settlements—for example, the LSA site of Ndondi Tossekel—with close affinities with the Dhar Tichitt phase labeled the Chebka/Arriane (1400–800 B.C.) has suggested to MacDonald (1994, 1996) that pronounced desiccation, along with, probably, pressure from nomadic neighbors, forced groups from the Dhar Tichitt area to expand southward into the Méma floodplain. McIntosh (1993) has proposed a "pulse model" in which he suggests that many of these southern Saharan and Sahelian ecological zones, in particular the natural water corridors,

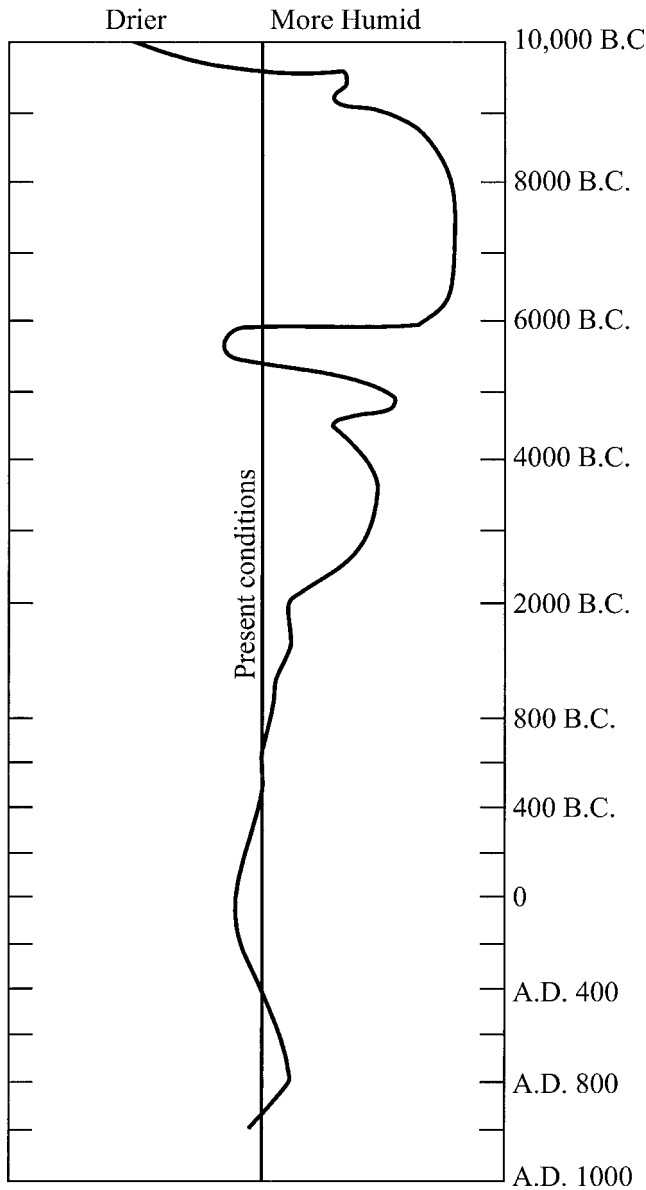

Figure 6.1. Holocene climatic fluctuations in West Africa.

would at times of human ecological stress have been locales for adaptation, early economic specialization, and ethnogenesis.

Although oscillations in precipitation and lake levels persisted, conditions somewhat improved, episodically, around 3500 B.P. in several areas of intertropical West Africa. After 2300 B.P. (300 B.C.), however, the climate went into serious decline (McIntosh 1983; Brooks 1986). The onset of these dry conditions is thought to have severely reduced the depth and extent of the annual Niger flood and to have enabled iron-using populations to penetrate and colonize permanently the deep floodplain of the Inland Niger Delta

(McIntosh and McIntosh 1980; Haskell, McIntosh, and McIntosh 1988; McIntosh 1995).

From A.D. 300 to A.D. 700, rainfall began to improve and remained favorable until the end of the first millennium A.D. (Brooks 1986; McIntosh 1983). The available archaeological data show that this period of optimum and relatively stable climatic conditions favored the establishment and development of dense and deep stratified sites in many regions of the Middle Niger, such as the Upper Niger Delta, the region of Timbuktu, and the Méma (McIntosh and McIntosh 1980; McIntosh and McIntosh 1986; Togola 1993, 1996; McIntosh 1995). Many of these settlements show evidence of complex society and participation in interregional trade networks (well before the trans-Saharan trade, to which long-distance trade had traditionally been ascribed). An important aspect of this intense occupation of the Middle Niger is the presence of clustered but simultaneously occupied sites (McIntosh and McIntosh 1980; McIntosh 1995; Haskell, McIntosh, and McIntosh 1988; Togola 1993, 1996). R. McIntosh (1991) has interpreted this clustering phenomenon as the expression of emerging urbanism and increasing specialization in the absence of centralized political formation. The onset of these wetter conditions also presumably played an important role in the development of the empire of Ghana in the first millennium A.D. in a region now so prohibitively dry. Excavations by Sophie Bethier (1997) have shown that the initial occupation at Kumbi Saleh, considered by many to have been the capital of Ghana, date to this climatic optimum, especially to the sixth century A.D.

Following the steady improvement of conditions from A.D. 300 to 700 were several hundred years of relatively stable, relatively rainy conditions. The wet phase of A.D. 700–1100 was followed by a downturn in rainfall (Brooks 1986; McIntosh 1993). Work in the Upper Niger Delta, especially in the Dia and Jenné areas, shows that many of the sites were abandoned at approximately A.D. 1000 or a few centuries later (McIntosh and McIntosh 1980; Haskell, McIntosh, and McIntosh 1988; McIntosh 1995). A study of the settlement history of the Méma has also shown that the majority of the Iron Age mounds were abandoned around A.D. 1300 because of the desiccation of the Fala de Molodo, a major distributary of the Niger that once flowed into the area (Togola 1993, 1996). The same phenomenon has been documented farther north in the region of Timbuktu (McIntosh and McIntosh 1986).

In general, rainfall patterns in intertropical Africa during the last four millennia of the Holocene show a downward trend. Superimposed on the general long-term variations are shorter climatic cycles extending over a century or over a few decades (McIntosh, this volume; Petit-Maire and Risier 1983; Petit-Maire 1986). In this context, the most recent Sahelian drought, which began in 1968 and continues to today, is not then an anomaly but rather the most recent of many. Whatever the regularity and duration of these small-scale variations, for the peoples of the Sahel they represent unpredictability and increasing reduction in available resources during the dry episodes. The salient characteristics of the climate today, particularly the

high interannual variability in rainfall and the difficulty of prediction from year to year, can be extrapolated back to prehistoric times. Stress and a steady reduction in available resources, as well as periodic famines and instances of social disorder, were constant and sad realities of the existence of the populations of the West African Sahel.

Memories and Abstraction of Past Environmental Changes

How have Sahelian communities perceived these past climatic and ecological changes, and how have they preserved and objectified memories of ecological stress? It is necessary to recall that climate changes occur episodically at various timescales and with varying intensity (Petit-Maire 1986; McIntosh 1993). Long-term global climatic change at geological scales are likely to be beyond the reach of social memories. Short humid/arid cycles (especially the dry episodes and their aftermath of food shortages and famines) that recur frequently are, however, more likely to influence the perception of a society and be impressed upon the memories of several generations.

The task for prehistorians, historians, and ethnographers is to identify the agents by which memories of past environmental disasters are preserved. These agents are not always narrated explicitly but may be embedded into both cultural and social values. The discussion below focuses on the myriad of legends, myths, and traditions used by Mande peoples to allude to past climate changes, especially drastic episodes of ecological stress that caused famines, depopulation, and social disorders.

The best-known of these legends is undoubtedly the legend of Wagadu, a region centered in the western Sahel, in what is now southern Mauritania and western Mali (see fig. 6.2). The kingdom of Wagadu is widely assumed to correspond to the empire of Ghana, said by historical sources to have been the first organized state in West Africa. The legend relates the diaspora of the Soninké, a northern Mande group and the founders of the Wagadu kingdom, under circumstances of ecological stress.

In this legend, Dinga, the mythical ancestor of all the Soninké, is said to have founded Kumbi Saleh, the capital of the Wagadu, after a long wandering that brought him, in some variants, from the Middle East to this Sahelian region. The guardian of this place (in other versions, his son), the sacred snake Bida, promised abundant rains and great quantities of gold, on the condition that the Soninké worship him and sacrifice the most beautiful virgin of the country to him every year at the beginning of the rainy season. Wagadu became powerful and prosperous as long as the Soninké paid this human tribute to the snake Bida. This prosperity was brusquely interrupted when, one year, a suitor of the virgin chosen to be scarified killed the black serpent Bida (Delafosse 1912; Monteil 1953; Bathily 1975). The killing of the sacred serpent caused a dreadful curse to be placed on the Wagadu. The

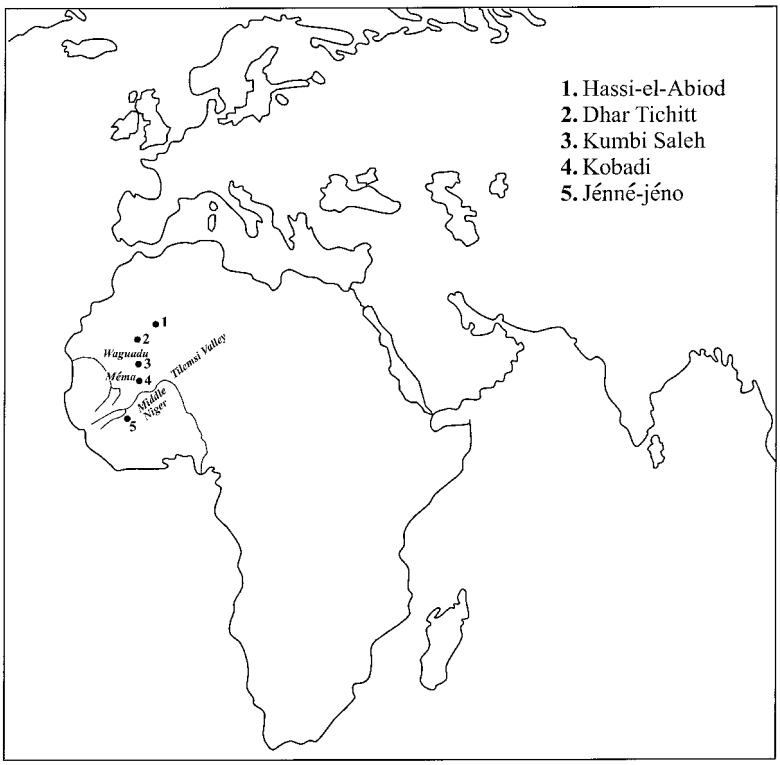

Figure 6.2. Major archaeological sites mentioned in the text.

country became desiccated. The flow of gold stopped. And the inhabitants of Wagadu soon dispersed throughout western Sudan.

As we know, the climate of this Sahelian region witnessed an increasing trend towards desertification during the later Holocene. The legend of Wagadu can be considered as a metaphorical representation of a real crisis event, probably a dry episode, and also of many such events. As the region lacks any surface water, the health of the area's human ecology must have been exclusively dependent on the annual rainfall. Considering such environmental stress, a southward movement of populations in search of moister regions is a reasonable possibility. Indeed the oral traditions tell of a massive shift of the Soninké, who are reputed to have founded many towns farther to the south including Dia, Jenné, Sansanding, and Markala, after the collapse of the kingdom of Wagadu (Delafosse 1912).

These kinds of population movements certainly commenced with the onset of increasing aridity and the period of desertification around 4500 B.P. The climatic fluctuations and in particular the overall southward migrations of rainfall isohyets and vegetation zones would have forced the populations on the Saharan margins to undertake short- or medium-range migrations. Smith (1979) reports that populations moved into and out of the Tilemsi Valley, a now-dry river channel running from the Adrar des Iforas to the Niger River near Gao, in response to rainfall oscillations. Several Arabic texts dating from 800 to 1650 A.D. describe more recent population shifts (Levtzion

1973). According to Webb (1995), Saharan nomads moved south and then north in pulses linked to rainfall oscillation. The effects of intersecting climatic periodicities and incursions of nomadic peoples from the Sahara resulted, for the Soninké, in a southward retreat. One of the most marked and certainly most decisive stages of this process was the Almoravid invasion that, according to the Arabic sources mentioned above, destroyed Ghana (presumed to correspond to Kumbi Saleh) at the end of the eleventh century (Cuoq 1975; Levtzion 1973).

In addition to these kinds of legends, constellations of myths among the Mande tell of times of economic stress and interethnic food aid during periods of crisis. One example tells how a Bozo father fed a hungry Dogon family with his own flesh, with the result of a perennial debt of Dogon support for their Bozo brethren (McIntosh 1993). Furthermore, many Mande traditions can help identify some of the small-scale climatic variations within time spans of a few hundred years. For example, among the Bambara there is a tradition of naming individuals or age groups after real crisis events (Bagayoko 1978). In the Baoulé Bend in Western Mali (where I recently conducted fieldwork), I found that the two most marked dry episodes of this century, the Sahelian drought and the 1913–14 drought (which was followed by locust devastations, harvest failure, and famines), are reflected in two age groups, the *nionblé si* and the *ton si*. "Nionblé si" refers to those circumcised during the year of "the red sorghum." This variety of sorghum, not seen before in Mali, was a substantial part of the food aid from the United States and Europe during the Sahel drought. The second group, the ton si, includes those circumcised during the year the locusts came. Kodio (pers. comm., 1995) reports a similar tradition in the Dogon country, where many children born during the 1913–1914 drought are called Ogulum (literally, "I survived the famine").

All these legends, myths, and traditions not only preserve memories of past environmental crises but also manifest cultural and social values that serve as shared, implicit messages about the various Mande groups' perceptions of ecological deterioration. Environmental crises, indeed all kinds of calamities, are not seen as natural phenomena. Rather, they occur as the consequences of peoples' or spirits' malevolent acts (an aspect of *nyama*, "vital force"). The legend of Wagadu illustrates this situation best in showing clearly the links between the cult of the snake and problems related to water availability. Here, benevolent spirit protection stops once a group member blasphemes or adopts an inappropriate behavior. Abstraction of an ecological crisis, similar to that in the legend of Wagadu, is prevalent in the modern ethnographic literature of the Mande people. For instance, Monteil (1953) reports that among the Bambara, the founder of the village (the analog to Dinga in the legend of Wagadu) often enters into contact with a spirit and establishes an alliance with him. The spirit then becomes the *dugu dassiri* (literally, "the protector of the village"). In exchange for sacrifices, it protects the village from severe disturbances, including ecological crises. In many places, especially along perennial rivers, the dugu dassiri is Faaro, an

androgynous being associated with the creation of the world and believed to live in water (Monteil 1953; Imperato 1982). Faaro, in Bambara belief, is in charge of maintaining the world in equilibrium and protecting it from calamities. Sheik Tidiane Hayidara (pers. comm., 1996) reports that hundreds of villages along the Niger River between Kouroussa in northern Guinea and Gao in northeastern Mali link their foundation with the presence and protection of Faaro.

Such an abstraction of the material world is extremely important as it provides an explanation for the resolution of the ecological crisis. As indicated above, one of the most logical coping strategies adopted during episodes of drought was temporary or permanent removal to better-watered areas. The Mande people's conceptualization of catastrophic events, however, including low precipitation cycles, and their attachment to their territory (because of the presence of protector spirits), certainly form the basis of strong resistance to any decision to make such a move. For instance, in one variant of the legend of Wagadu, the Soninké endured "seven years, seven months, and seven days" of severe drought before retreating out of the Wagadu. Where would the community retreat to? Would this new landscape be peaceful and prosperous? Considering these uncertainties, it is not surprising that in many Mande legends the shift to new territories often involves persuasion by individuals believed to possess special intellectual and spiritual capacities and an enormous amount of *dalilu*, or supernatural power. These individuals, like Dinga, use their special knowledge and special powers to make alliances with spirits, who then help them to liberate propitious lands for the group's settlement. These individuals, referred to as "Men of Crisis" by R. McIntosh in this volume, include hunters and blacksmiths.

The most important among them is certainly the *komotigi* (literally, the leader of the Komo society, a secret and religious society that, until recent and massive Islamization, was widespread among most Mande peoples, in particular the Bambara and Malinké). From the number and variety of the tasks of the komotigi, it follows that the Komo is extremely important in Bambara life. The komotigi, generally a blacksmith, has the ability to see into the future. He can cure the sick and make charms to protect people from spirits' malevolent acts and many other perils. The komotigi is also an astrologer and a meteorologist. He studies the skies and interprets the positions of the most visible celestial bodies, such as the sun, the moon, and the most important constellations. He is also an expert in the behavior of animals and plants. His astrological knowledge and his observation of animals and plants allow him to predict whether the rains will come at the expected times. In response to environmental crisis, the komotigi makes charms to protect the harvest from drought and pest attacks. Dierterlen and Cissé (1972) report that some komotigi are even able to bring down the rain and suspend it at their will. In these ways, the Komo helps the Mande peoples to control the unpredictable Sahelo-Sudanic zone in which they live.

By the time the recent Sahelian drought commenced, the Komo was in

serious decline; indeed, the institution had disappeared from many Bambara areas. Many communities had turned to the *marabouts*, the holy men of Islam, who are believed to possess supernatural power similar to that of the komotigi. The marabouts' abilities to protect the crops against the drought were not up to the population's expectations, however (McNaughton 1988). During a recent trip to my home area in the Cercle de Bougouni (southern Mali), I found that some of the villages, like Koumantou, had returned to Komo. Some repositories of social memory can be rediscovered under altered circumstances.

The perennial question is whether it would be possible to identify in the archaeological record the codes, signs, and material signals used to express all these social and cultural values. In other words, if the beliefs in the special knowledge and power of the smiths and the Komo indeed have a long history among the Mande, what kinds of material metaphors found in the archaeology of these places would invoke them? Answers to this question are not easily found, because many of the values discussed in this paper, in particular the myths and legends, are in the domain of ethnography and ethnohistory. Nevertheless, the experience of prehistorians, as well as of art historians and symbolic anthropologists, is that deeply held social and cultural values are commonly reinforced by material metaphors (McIntosh 1991, 1993). In addition, some classes of archaeological materials, such as art objects, can be very communicative of the ideology and social realities held by the communities who made them. For example, careful excavations at Jenné-jeno have shown that some elements of the Inland Niger Delta's rich terra-cotta statuary were used in problem resolution. Among these were examples of protective figurines purposefully buried in walls near house entrances (McIntosh and McIntosh 1988; McIntosh 1995). The most fascinating example was a pair of terra-cotta figurines associated with a rainmaking altar made from sandstone slabs and iron rods. According to the McIntoshes' local informants, blacksmiths still use similar shrines during rainmaking ceremonies (McIntosh 1995).

It is also worthwhile to note that southern and central Bambara country (especially the regions of Bougouni, Dioíla, and Kolondiéba) has produced hundreds of terra-cotta figurines with impressive stylistic variability (Togola 1982). As these art objects were plundered and lack stratigraphic and chronological context, however, there are no remaining clues as to their communicative role, their relationship with modern Bambara statuary, and their use in problem resolution. Similarly, though many of the oral traditions hold the Komo to be at least as old as the empire of Mali (linking it to Fakoli, a blacksmith and strategist of Sunjata), there are no archaeological data on what the early sculpture of the Komo might have been. Today, the most sacred element of the Bambara's statuary art is the mask of the Komo. It is generally carved in wood and covered with many animal materials, such as hair and bird feathers. Except for sanctioned ceremonies, attended only by initiates, the Komo mask, and all the elements associated with it, are secreted away

outside the village in a special shrine (generally located in a wooded area) or in the home of the Komo leader.

Concluding Remarks

The messages that function as abstractions about causality in the material world contained in the constellations of myths and legends discussed in this paper provide for the Mande a general explanatory framework for ecological crisis in the Sahel and savanna belts of western Africa. It seems intuitively clear that such a complex perception of ecological crisis has its roots in the remote past. But among modern peoples too, these perceptions are still relevant, especially in explaining the ecological crisis of the last two decades. Thus the ideology and belief systems of the Mande are part of the coping strategies adopted during the episodes of environmental crisis. I have tentatively suggested that many of the codes, signs, and metaphors used to communicate the social perception of environmental crisis can also be identified in the archaeological record.

We are at the very beginning of the archaeological exploration of the vast territory occupied by the Mande. Ethnography, art history, and the study of oral traditions have great (and as yet untapped) potential to alert the archaeologist to the ways in which the material world was shaped into codes and signs of social memory by the ancestors of the Mande. Archaeology ultimately will hold the key to how such signs (and the deeper values at their foundation) changed and evolved through time, as these populations adapted to the special challenges of arid, lowland tropical West Africa.

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Chapter 7

From Garden to Globe: Linking Time and Space with Meaning and Memory

Carole L. Crumley

Space, Time, and Mind in Gardens and Landscapes

Social memory is the means by which knowledge is transmitted from one generation to another. Individuals, not necessarily aware that they are doing so, pass on their behaviors and attitudes to younger members of their culture. To use an analogy from physics, social memory acts like a carrier wave, delivering knowledge across generations, regardless of the degree to which participants are aware of their role in the process.

Like a coaxial cable on the ocean floor, bundles of cultural information are arranged around a central concept. Manifested as both a practice and an ideal, such concepts prompt people to construct a variety of reasons for their existence. This multiplicity of rationales for engaging in certain practices ensures the transmission of fundamental information but also leaves room for individual differences in experience, perception, and conviction.

The idea of the *garden*, the many rationales for which range from practical utility to cosmic meaning, is such a concept. At a more inclusive scale, *landscape* is similarly rich, both in meaning and in concrete reality. Landscape is the visual signature of a territory (a vista) that is partly formed by the people who inhabit it.

The information contained in gardens and landscapes is conserved in the character and spatial arrangement of their respective elements. Arranged in patches or mosaics and distributed through time and across space, these elements constitute practical units of analysis. Examples of garden elements would be an heirloom medicinal plant or lettuce beds; a landscape element might be a woodlot or a moor. Inasmuch as initial conditions support and constrain human activity, these elements reflect both the distant and recent history of the human-environment relation. The focus on elements and their

relations to one another enables pattern recognition at any spatial scale: from that of the micororganism to regional and ecological zones (Hammett 1992; O'Neill et al. 1991; Pielou 1975, 1984) and even more broadly to phenomena at the continental (e.g., airmass patterns) and global (ozone layer) level (Gunn 1994; Turner, Dale, and Gardner 1989).

In addition to history (time) and geography (space), cognition is a third important dimension of the analysis. For example, in cultures where class differences are marked, elite gardens—comprised of flowers, trees, and shrubbery—serve symbolically as miniature landscapes; they display and enhance status and are sources of pleasure, not subsistence (Leone 1984, 1988). Employed almost like stage sets, pleasure gardens manifest individual attempts to transmit identity, taste, and style (Le Dantec and Le Dantec 1990; Pugh 1988; Thacker 1979); like all dramatic creations, they are subject to marked shifts in fashion.

If pleasure gardens are theaters, then vernacular gardens are schools. The vernacular (from the Latin word for "native") garden is a conservative form, home to a mix of vegetables, fruit trees, and other elements useful in the maintenance of the household (Hunt and Wolschke-Buhlmahn 1993; Miller and Gleason 1994). The English term *garden* (French *jardin*) has vulgate Latin (*gardinum*), Teutonic, and Norse roots (*garth*), the last of which defines "a small piece of enclosed ground, usually beside a house or other building, used as a yard, garden, or paddock" (*Oxford English Dictionary* 1971:1118; see also Erp-Houtepan 1986). Vernacular gardens are herein defined as plots in which plants are tended by hand that form part of the domestic economy. Vernacular gardens sustain traditions, store hard-won solutions to local conditions, and represent real household wealth. Both vernacular and pleasure gardens represent in miniature a vision of the owner's cosmic order, but in the vernacular garden the gardener who labors and the owner who enjoys are usually one and the same.

The complex ways gardens are used and what they represent explain some of their enduring fascination. Gardens' historic importance during hard times; their convenience, quality, and economy; and the control they offer over the circumstances of production make them much valued in traditional societies.

Gardens are also places of recreation, creative personal expression, and escape; to many, their gardens represent a resistance to pesticides and the industrialized production of food. Household gardens (and the resulting stocked larders) reduce anxiety and encourage practical experimentation. They encourage reflection on larger issues of family, history, and providence; they inevitably represent, in the most immediate fashion, the rhythms of lives lived with the seasons and with death.

Because of vernacular gardens' diverse benefits and central role in traditional societies, they offer a rich, personalized mnemonic that is "good to think" (Lévi-Strauss 1963:89; see also Francis and Hester 1990). The greater the range of thoughts and behaviors and the richer the meanings that concepts such as the garden evoke, the greater the likelihood that diverse infor-

mation bundled around that concept will be transmitted. In the same way that a cable gains strength from myriad individual strands, the more reasons there are to value the garden the more likely it is that its messages will be transmitted.

In the vernacular garden, complex information about ecosystems and practices that ensure their maintenance are adapted to the region and the locale. This knowledge passes from one generation to another out of sentiment as well as good sense: vernacular gardening is an intimate activity, and kin share both the work and the harvest. Vernacular gardens act as reservoirs of ecological knowledge and social practice.

So too do landscapes. Unlike vernacular gardens, entire landscapes are rarely molded by a single person; instead, they preserve the record of many individual actions, ideas, and societal practices. Even when elites have the means to alter many aspects of the countryside, others are still free to attach their own meaning to various landscape elements and spaces and turn them to other uses (Marquardt and Crumley 1987; Crumley and Marquardt 1990; Dunbar 1991; Schama 1995). Vigilance and stiff punishment have never been enough to ensure that even a royal preserve could be kept safe from poachers and gleaners.

Elites can adorn their estates with exotic plants and animals and create or modify bodies of water, forests, and fields, but such activities are usually limited to their places of residence. An exception is when disparate properties are owned and rented out or the land is put up as collateral; then, the renter or debtor may be obliged to follow the wishes of a sometimes distant and ill-informed landlord or deed holder.

Institutions can shape landscapes by replicating activities in several locations. For example, religious institutions are frequently large landowners. It is estimated that during certain periods of the Middle Ages, the church owned over 50 percent of the land in France. Monastic orders and royal estates, while engaged in essentially the same kinds of activities as surrounding farms, nonetheless undertook them on a scale far beyond that of farm families (Harvey 1981). Former royal and monastic holdings can still be discerned on the French landscape from the air, although ecclesiastical policy and royal privilege are no longer major influences in shaping the landscape.

More fundamental to the shaping of landscapes and more enduring are activities associated with widespread patterns of subsistence. This is because many individuals and families, not just elites, find utility in the same elements of the landscape and foster their continuity from generation to generation. In contrast to industrial agriculture, in which particular crops or animals are raised exclusively for market, traditional farming meets the majority of domestic subsistence needs (Netting 1993). Vegetables, cereals, meat, and condiments are produced on the farm, most of them (excepting grains and herd animals) within steps of the farmhouse door. In the absence of electricity and community water supplies, a farm's woodlot, springs, and ponds provide heat, light, and water.

Spatial concerns are central to the efficient management of all farms, but

they are especially important on traditional farms, where numerous daily activities are the responsibility of relatively few individuals. Frequent tasks must be undertaken as close to one another and to home as possible. The less frequent the activity, the further it can be from the home (von Thunen 1966; Chisholm 1962). Over generations, the spatial organization of farms in a region becomes consistent with a particular suite of activities, and the landscape takes on a visible regularity.

Learning Burgundy

Since my research group began working in Burgundy in 1975, we have examined changes in settlement, economy, environment, and demography that historic, long-term shifts in the Western European ecotones have entailed. From these data, we have projected changes that might accompany contemporary global warming. We have monitored contemporary practices that count as ecological successes (gardening) and as failures (extensive gravel mining in river valleys).

Our research methods include archaeology, a variety of paleoenvironmental studies, the analysis of maps and documents, and ethnography. We have interviewed dozens of gardeners and farmers and amassed documentary evidence for older plants and practices (e.g., from almanacs). We have three millennia of archaeological evidence for biota, land use, and settlement and over three centuries of detailed population data.

We have accumulated an extensive biophysical and social science database (Crumley and Marquardt 1987). The spatial data are aggregated into a Geographic Information System with over a hundred layers (Madry and Rakos 1996). Since the 1970s, we have been accumulating LANDSAT and SPOT imagery of the region, as well as data from AIRES and other scanners. We have digitized a variety of contemporary and historic maps (the earliest from 1759). This extensive information offers a unique opportunity to look closely at how the region's economies, both domestic and industrial, have been sustained for the past two thousand years.

Like most French householders, both rural and urban Burgundians have gardens despite the ready availability of produce in stores and at open-air markets. This tradition of domestic production appears to be unbroken as far back as at least the first millenniumB.C. and offers a remarkable opportunity to study the role gardens have played in allowing households a means of autonomous adaptation to social upheaval and Burgundy's unpredictable weather.

Gardens play a critical role in reducing risks associated with inclement weather all over the world. Unlike field crops, gardens shelter numerous species in special soils and under controlled microclimatic conditions. Plants receive individual attention and enable the gardener to develop an intimate understanding of soils, winds, and seasons as they relate to the garden plot.

In addition to abundant produce, gardens both conserve traditional species and are filled with small experiments that yield new information.

The climate of Europe is the result of the dynamic interaction of three major climatic regimes. The temperate *oceanic* regime (sometimes called the Atlantic) characterizes the northwest quarter of the continent and carries moisture inland from the ocean; under present global conditions, this pattern dominates in the spring and fall. The subtropical *Mediterranean* regime characterizes the circum-Mediterranean littoral and North Africa and brings dry, desert winds north; this regime dominates primarily in late summer. The temperate *continental* regime dominates northeast Europe from the Siberian high and carries dry air west from the interior of the continent, primarily in winter. Burgundy sits at this climatic "triple point," and a look at the region's climate history reveals that the boundary between the temperate systems and the subtropical system (termed an ecotone) has shifted hundreds of kilometers in response to extended periods of globally cool (southward movement) or globally warm (northward movement) conditions (Crumley 1987c, 1993, 1994, 1995a, 1995b, n.d.; Gunn 1994; Gunn and Crumley 1991; Magny 1995; Richard and Magny 1992). The ecotone's historic movements provide a model to anticipate the specific conditions global warming will cause in a key food-producing region of the world.

In addition to raising global temperature and repositioning climatic regimes, certain greenhouse gases will increase seasonal slippage ("unseasonal" weather), variability in regional weather patterns, and extreme events such as powerful storms and hail (Camuffo and Enzi 1992:153). Since Burgundians have for centuries been forced to anticipate such conditions and to rally in their wake, traditional strategies are of particular interest.

The ecotone has traversed Burgundy several times in the past three millennia; its movements can be traced by means of physical evidence (sediment erosion and deposition, movement of plant communities) and archaeological and documentary evidence (changes in subsistence strategies, ecclesiastical records). Each time, the region's broken terrain and its human population have enabled some stressed species to find refugia in wild places and cultivated spaces. These historic examples demonstrate that the human population's ability to adjust to environmental change is closely tied to biotic and economic diversity.

Burgundy's physical environment is as remarkable and complex as its weather and climate. Its basement rock records a distant geological history that includes periods of marine transgression and mountain building; more recent sediments in the rivers and lakes reflect a combination of human activity and environmental change. The varied and much-modified geology and broken terrain of Burgundy yield a landscape in which microclimatic conditions play a crucial part in the success of plant and animal communities. While a locale may benefit from high-quality soils or abundant rainfall, advantages are easily offset by other circumstances, such as less favorable exposures or increased danger of frost and freeze.

Despite environmentally precarious periods in the region's history, Burgundy has nonetheless enjoyed considerable economic prosperity because of its geographical position. The primary river systems of Western Europe either rise in Burgundy (the Seine) or flow through it (the Loire, the Rhône-Saône river system). This has ensured the region's importance for millennia as a zone of transit and a center of commerce. There is evidence of Upper Paleolithic horse hunters and cave artists, and the importance of agriculture and stock raising, practiced for the past sixty-five hundred years, continues to the present in Charolais beef cattle and quarterhorse farms, vineyards, and the production of other specialties such as mustard and goat cheese.

Extraction of natural resources (gold, tin, iron) and manufacturing goods from them have been a major part of the region's economy for three millennia; by two thousand years ago Burgundian steel weapons were being purchased to equip the Roman army. From the tenth to the fifteenth centuries, the dukes of Burgundy were synonymous with Western European cultural refinement and political power. At the end of the nineteenth century, Burgundy was at the heart of European industry; the region's iron, coal, and oil resources subsequently fueled World War I. Nazi occupation in World War II and the extraction of radioactive materials in the 1950s further underscore the region's enduring strategic importance, both in terms of its geographical situation and its varied resources.

Disastrous late spring and early fall freezes, torrential rains, softball-sized hail, and extended droughts have all beset Burgundy at one time or another since we began working there over two decades ago. Historical records (from as early as 1645 and 1710) document similar circumstances, although it is clear that some periods were worse than others. Farmers accurately recount the years in which cold or drought or floods took their toll, and they retell relatives' weather tales from as far back as the late nineteenth century. One man, an amateur historian, knows the harshest winters and famine summers well into the eighteenth century.

It is for good reason that rural people know the region's various microclimates well enough to draw them on a map. Features such as a hill that both breaks the wind and produces a rain shadow or the elevation-related distribution of chestnut and cherry trees give every farm its distinct microclimate. Gardening and farming philosophy, captured in sayings (*dict-ons*), aids the transmission of information by encouraging the recognition of and response to conditions. Burgundian farmers and gardeners are keen observers of the weather, with a long tradition of weather-related sayings (Labrunie 1984; Taverdet and Dumas 1984). Many sayings are tied to the seasons through the calendar of saints' days or the phases of the moon. The "ice saints" warn of the danger of a killing frost until mid-May; wood fashioned into tools during the dark of the moon will be wormy. To know in advance about changes in the weather, one farmer asserts, one must simply "read the animals, which are no more beastly than humans."

Most people say they know the sayings and that there is "something to them" but that they don't slavishly follow the advice or expect the predic-

tions necessarily to prove accurate. The sayings serve as reminders, not laws, and produce reflection on the situation at hand but not necessarily a particular action. Such observations, gained from the close scrutiny of all living things and of the land, serve as indicators of well-being for farmer and gardener alike. Familiarity with all aspects of the mutable Burgundian environment has made possible the long tenure of gardening, farming, and pastoralism in this landscape.

Lessons from the Garden in Husbanding Diversity

Research on the principles of intensive gardening practiced in the region (Crumley 1995b) identifies three critical elements. The *selection* of a particular suite of plants and animals has, over time, resulted in the traditional husbandry of species that have tolerance for a relatively broad range of conditions. Furthermore, the *wide repertoire* of species in local gardens ensures differential impact. Because a cool summer is better for cabbage than for garlic and a cold winter impacts rabbits less than pigeons, it would be a rare year that *all* husbanded plants and animals failed to thrive. Finally, the *planting and harvest cycle* allows for regular adjustments of the enterprise as conditions (e.g., seasonal slippage, weather events) change. These lessons can be summarized from the practice of nearly any Burgundian gardener: retired factory workers, suburban gardeners, and Charolais beef cattle farmers report very similar tactics.

Most Burgundian gardens have more than thirty species of vegetables, many (such as lettuce and beans) represented by several diversely tolerant varieties. In addition there are fruit trees and berry bushes (at least three or four species each), flowers, and herbs (tastes vary, but there are rarely fewer than five or six kinds). There are usually several categories of "special plants," family heirlooms such as arquebuses or exotics. Some people raise small stands of rye to attract pheasants, and a few still have grapevines, although nowadays vines are stringently regulated.

Today people buy their seed, bulbs, and plants; they also continue to save and trade with neighbors, as was common in the past. Historically, there were fewer species and varieties than there are today, but microclimatic differences from one farm to another ensured genetic diversity; trading was especially important, and stocks from outside the region were rarely purchased. Today, there are plentiful varieties and species available through catalogs, but these designer plants encourage the abandonment of less photogenic traditional varieties and the substitution of less genetically diverse stocks.

Animals are an integral part of these gardens, and many include several varieties of chickens, ducks, and geese; cages for pigeons, rabbits, and snails; and hives for bees. The farmers' larger domesticated animals include (besides the Charolais cattle) goats, pigs, sheep, and (only occasionally since the advent of tractors) horses.

In addition to harvesting their gardens, people range across fields and

through woods. They hunt mushrooms and pick several species of wild plants, either for consumption or to make natural pesticides. This latter practice is only one of a dozen ingenious and nontoxic means of controlling insects that employ household staples such as mustard, milk, and salt. Some remedies require the assistance of other garden denizens, such as releasing a turkey in the potato patch to eat potato bugs.

Garden soil is improved with spade work, aeration, constant weeding, the dung of horses and cattle, and (less frequently) the droppings of some of the caged animals. The location of smaller plants (such as radishes and lettuce) in the garden is changed each time they are replanted (about every six weeks), and a three-year round is employed for more extensive plantings of cabbage, potatoes, and clover. The latter serves as food for the rabbits.

The planting rhythm is tied to the seasons and reflects both the species diversity and the uncertain weather. Several vegetables, such as radishes, carrots, lettuce, and beans, are planted every ten days so they may be harvested continually, providing protection from complete loss and the opportunity to adjust the species planted to the shifting weather patterns. Before the freezes end, many people start smaller garden plants in a cold frame or greenhouse and then move them to the garden when the threat of frost is past.

Changing Landscape Units: Farmyard, Pasture, Field, and Wood

Burgundian farmers must think at more encompassing scales than that of the garden. In some regards, the farmer's control over many hectares of pastures, fields, hedgerows, woods, and ponds resembles that of the estate owner. There are, however, several differences. Farmers cannot follow whimsy any more than can serious gardeners; rather, they must engage in careful calculations that sustain the profitability of the land. Large bank loans mean that their land, farm equipment, crops, or animals may not be entirely theirs to deploy. Thus the bottom line is whether the operation of the farm is profitable and allows the farmer to service his debt.

The European Community's Common Agricultural Policy (CAP) and the 1992 General Agreement on Tariffs and Trade (GATT) were hotly contested by farmers as well as other groups. While these agreements have been examined in terms of economic costs and benefits at several levels, there has been very little research on their effects on the landscape and other changes they have entailed.

Market conditions are forcing Charolais beef farmers to adopt practices completely counter to ecologically sensible customs handed down for generations. For example, the soil, vegetation, and moisture characteristics of Burgundian pasturage counsel a ratio of one animal per hectare; this calculus has been scrupulously respected for centuries. The CAP and the GATT have forced farmers to violate this calculus; in order to remain competitive, they have expanded their herds to compensate for lower market prices.

Larger herds require larger pastures and larger farms, and the number of animals per hectare has increased. Farmers began buying the land around vacant farms and digging up the sheltering hedgerows. Fewer hedgerows mean less shelter for cattle and ultimately more bovine health problems, a reduction in wildlife and noncultivated species, less plant diversity in the pastures, and more erosion. In order to reduce costs further to stay competitive, the remaining large farms require more hectares in cereals and fodder and ultimately more herbicides. This further deteriorates a key relationship between wild and domesticated species, threatens irreversible degradation of the Burgundian landscape, and risks failure in the transmission of ecological stewardship.

In addition to hedgerows, other familiar elements of the landscape are also changing. Woodlots and forests, once characterized by a great variety of deciduous species and some conifers, have begun to be replaced by single-species commercial conifer plantations or to be transformed into pastureland. Since 1945, and even more aggressively since the 1980s, conifer plantations have been encouraged by the French government, which subsidizes the purchase of both land and seedlings. Like the loss of hedgerows, the disappearance of woodlands impacts wildlife and noncultivated species. Traditionally, these woodlands were located in less fertile upland areas. If converted to field or pasture, there is greater likelihood of an increase in erosion and ambient environmental toxins. Plantations of single-species conifers also decrease wildlife habitats, and many farmers are convinced that the different reflective properties of conifers have the capacity to change local climate.

Especially instructive is the disappearance of the *ouche*. The word is of Indo-European derivation, and its current French form is derived from the Gaulish **olca*. It is briefly defined in dictionaries of Old French as "a field of good quality (sometimes an orchard) near the farmhouse." What elements constitute an ouche? I asked several older residents. It is an area very near the farmhouse, usually about an are (100 square meters) in size. It is often, but not always, fenced. Frequently, a source of good water (a spring or a well) is present. It has fruit and nut trees (such as cherry and chestnut) that can shelter such things as rabbit pens; coops for chickens, ducks, and other fowl; pigeon lofts; cages for snails; or a small shelter (a shed or *crèche*, a manger or crib) for tending small or sick animals. Grass covers a part of the area. An ouche includes or is contiguous with the family *potager* (kitchen garden). A part of the ouche is often made into the overflow garden, where plants that require greater space and less care (like potatoes or cabbage) are grown. There is always a compost pile, sometimes a toolshed, and before indoor plumbing there would have been an outhouse, shielded from sight by vegetation and located at one of the ouche's outer edges. Ouches can be part of, but may be distinguished from, the elements and spaces that constitute a farmyard; those would include buildings and turnarounds for large equipment, silos, and livestock barns.

I first heard the word in an interview I taped with a farmer about his garden; I looked it up in my big Oxford Hachette dictionary, but it wasn't there.

Inquiries of linguist colleagues (Melchert, pers. comm.; Eska, pers. comm.) soon uncovered the word's five-thousand-year-long history, which reaches back to the Indo-Europeans, the earliest agropastoral people in Europe.

Excited about stumbling on an element of the landscape that has endured for several thousand years, I asked my friend Dauvergne to take me to see ouches. His family has farmed in the commune (an administrative division) of Uxeau (a Celtic word meaning "high defended place") for centuries. That afternoon we visited the sites of a half dozen he knew about; disappointingly, every one had been quite recently transformed into a pasture or field or put to other uses.

I did eventually see a few ouches. Their owners assured me that proper maintenance of the ouche had been discontinued only recently. Many ouches, albeit in disrepair, still had their fences; fruit and nut trees still stood, and in some there were still rabbit pens and potato patches. One tumbledown crèche now sheltered a cat and her kittens.

What does it mean that ouches have quite recently begun to disappear from the Burgundian landscape? There are a few potential causes for their demise that our historical knowledge allows us to eliminate. It cannot be directly the result of rural exodus, which accelerated with urban industrialization in the mid-nineteenth century and, at least in Burgundy, has now slowed to a trickle. Some rural communes are even gaining population, although this is due primarily to the proliferation of secondary residences and the rural homes of office workers and retirees. It is not a result of rural mechanization; tractors, combines, and the like have been utilized since just after World War II.

The demise of the ouche most directly is tied to abandonment of the principle of diversity (Holling 1986). While Charolais herds have been a primary farm commodity for three centuries, it is only since the 1970s that Burgundian farmers have specialized in the production of Charolais beef for the world market and begun to increase the size of their herds. As herd size increased, both the production for sale of other farm products and the number of working farms diminished; abandoned farmhouses or ones with nonfarming inhabitants became more common, and surrounding lands were bought up to accommodate the larger herds. Other factors that have diminished the ouche's importance are the increased regulation of farm production for sale and the proliferation since the 1970s of supermarkets, where chickens, eggs, and other produce can be easily and cheaply obtained (Crumley 1987d).

After over five thousand years, the ouche, emblematic of sustained agropastoral production in a temperate environment, has outlived its usefulness. Diversity, tied for so long to climate and geology and domestic independence, has been sacrificed to international competition and government regulation. The irony is that Burgundian farmers understand what remaining economically viable has and could cost.

At least once before Burgundy's diversity has been compromised. Bur-

gundy enjoyed a remarkably stable period of dry summers and mild, rainy winters from about 300 B.C. to A.D. 200; characterized by the dominance of the Mediterranean climate regime, this period is called the Roman Climate Optimum. When the Romans conquered Gaul in 58 B.C., many independent Gaulish polities were made provinces of the Roman Empire. Among them were the Aedui, who inhabited what is now Burgundy.

While the Romans treated some polities harshly, the Aedui, with a strong pro-Roman faction and undeniable economic importance, were spared (Crumley 1987a). They had been leading exporters of diverse products, among them iron and horses for the Roman army, wool for garments, and cured hams for Roman tables. Since both metallurgy and grazing animals diminish forest growth, pigs were raised in places where woodlands were protected (Druidic sacred groves, family woodlots).

The trade-off for Roman leniency was that Burgundy became a producer of grains, breadbasket for the great cities of the empire. The Burgundian landscape in the Roman period was comprised of single-crop fields sown for export. Agricultural *villae*, farms owned by Roman or Romanized elites, appeared in the river valleys where horses had grazed; slaves and the landless planted wheat, millet, and barley. Mining operations were moved to other provinces (Spain and the area around Bourges); suppliers of horses were found nearer military challenges at the empire's ever-more-distant margins. The sacred groves were razed, simultaneously supplying the Roman navy with ships' timber and weakening Druidic power.

When the long period of stable climate ended in the middle of the second century A.D., the indeterminacies of the more typical temperate pattern returned. As climate worsened between A.D. 500 and A.D. 900 (the period sometimes termed the Dark Ages), human misery was intensified by plagues, famines, and wars. Our regional geological investigations indicate widespread late antique and early medieval erosion and flooding (Straffin 1998), in probability accompanied by an increase in hail and unseasonal frosts. As key elements in the rural economic system collapsed, debt cascaded through the social order. As the region's economy moved into a crisis, the stage was set for Burgundy's role in the spread of feudalism (essentially permanent debt labor) throughout Europe.

Economic and social disruption were the result of many factors, but chief among them was a marked reduction in economic diversity, coupled with a major change in climate. The socioeconomic system's flexibility and its resilience in the face of adversity had been destroyed; it would be several hundred years before Burgundy's prosperity was restored.

The Past Teaches, the Future Learns: Policy Implications

Why should particularistic regional histories matter today? Burgundy's past can teach two important lessons, both applicable in any time or place. The

first is the importance of *diversity*, the second is that of *scale*. In many contexts—biological, economic, social, political—resilience in the system as a whole depends on the variety and flexibility of its constituent units. In human societies, the ability to endure by changing the scale of the endeavor is fundamental.

Because each region and locality have their particular characteristics, solutions that are workable in one place are not necessarily appropriate elsewhere. In Burgundy, historic landscape elements—the garden, the ouche, and the woodlot—have coevolved to accommodate the parameters of both local variation in weather patterns and long-term regional climatic change. These landscape elements are the result of centuries of experimentation, and they carry information about workable solutions to environmental uncertainty (Gunn 1994); they are the key to sustainability in that specific region. The web of plant and animal life they support has also coevolved, including mosaics of domestic and wild species that are resilient in extreme conditions; nonetheless, such systems have real limits.

The study of Burgundian climatic and environmental history reveals real thresholds that, when breached, crash the entire system. The social memory of Burgundy's inhabitants and our own ecological investigations indicate that these delicate relationships and their disastrous results are well understood. Older farmers are familiar with the false economies (reliance on too few species), landscape transgressions (widespread upland clearing), or weather patterns (extended drought followed by heavy rains) that caused past disasters. In more distant times, government edicts spelled ruin. Roman policy concentrated production in specific provinces; these regions became less diverse biologically, economically, and socially. Subsequent climatic deterioration, in concert with the diminished resilience of the social fabric, ushered in the Dark Age and the rise of feudalism (Crumley 1993, 1994).

The source of biological diversity resides in slight differences in the genetic material of varieties and species and their differential representation in populations; those organisms able to survive, temporally and spatially, specific onslaughts of pests, disease, or inclement weather pass that ability on to the next generation. Experimentation in gardens, the diversity of farm activity, and the maintenance of wildlife habitats retains these qualities at the landscape scale; the extensive cultivation or husbandry of selected species and the use of seed and breeding stocks that have been genetically altered do not.

In France, industrialized agriculture has already taken a measurable toll on many traditional activities: hunters must belong to a club that wins the collective right to kill a deer or a boar; squirrels are an endangered species. One can drive for miles in the grain belt of central France without seeing woods or even trees; as far as the eye can see, huge fields are planted with genetically altered cereals that are dependent on fertilizers and pesticides and cannot reproduce.

It is well known that French farmers have been among the most vocal in resisting the industrialization of agriculture and the necessity to compete in

global markets without governmental protection, but it is also true that they have had little choice. They must try to compete with their counterparts in Australia, South Africa, and Canada if their enterprises are to remain economically viable.

The global marketplace and the race to form a single global economy is something the Romans would have recognized. Managed by distant state authority, the biological and economic diversity of huge regions is subjugated in order to feed landless urban populations. Such was the Roman paradigm long before it was that of state collectives in the USSR and China or international cartels such as GATT and CAP.

In contrast to the global economy, economies of scale fit the conditions of their existence and retain plans for coping with distant as well as more local disasters. These smallholders (Netting 1993) organize their domestic economy heterarchically, that is to say, no single element (resource, strategy) is permanently ranked in importance above others, and diversity is valued (Crumley 1979, 1987b, 1995c; Crumley and Marquardt 1987; Ehrenreich, Crumley, and Levy 1995).

It is not just domestic economies that value the flexibility that diversification brings. Many businesses, small and large, have discovered the merits of heterarchical power relations that place decision-making power on the shop floor as well as in the board room; this recognition of workers' "indigenous knowledge" increases efficiency, employee loyalty, and production (Wheatley 1992). Investment houses counsel diversification of stock portfolios to smooth out market downturns. Omnivorous diet and diverse habitats gave even our early hominid ancestors a competitive advantage in changing conditions.

How can these lessons be applied to the contemporary world? If heterarchical organization and biological and economic diversity are the preferred strategies for managing uncertainty, the question must be, How uncertain are these times?

There are several important sources of uncertainty in the global economy. One is climatic instability, brought on by global warming. It has become clear that a warmer world will increase destructive, regionally and locally specific weather phenomena (hurricanes, floods, droughts, and perhaps even seismic activity) and disrupt seasonal patterns (Davis and Sellers 1994; Gunn, Folan, and Robichaux 1995), making weather in many parts of the world as capricious as that in Burgundy. These events will in turn affect financial markets, insurance, law, agriculture, tourism, and health (World Climate Programme 1997).

Another uncertainty is the very connectedness of global markets. Never in world history have so many economies been tied together. During the recent Asian market crash (fall 1997), U.S. investor confidence in a strong national economy and automatic buy programs stabilized the market. There remains, however, the danger that automatic corrections will not always be able to forestall the effect of investor flight, sending the global economy into free fall.

A third uncertainty is political. Armed conflict and natural disaster do not just threaten regional and national stability; refugees crossing national borders to escape fighting or famine, the threat of pandemic disease, and the international arms market (to name a few) spread the effects of conflict and disaster far beyond their places of origin.

What is sure is that however efficient industrialized agriculture is in the short term, its undervaluation of biological and economic diversity renders it a brittle structure. Agribusiness is everywhere maintained by means of expensive technology (genetic breeding, chemical fertilizers); in Europe, it is engaged in an aggressive campaign to ban traditional seed stocks. In the uncertain times that global warming will bring, global agribusiness, in its present form, will be unable to feed the world's population. No new technology can buy us the time to relearn what tradition—human memory and the memory in the land itself—has to teach.

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Chapter 8

Chinese Attitudes Toward Climate

Cho-yun Hsu

Social memory is formed and transmitted in all types of societies, from hunter-gatherers to great civilizations. The case of China represents the longest documented continuum of social memory in human history. Parts of the Chinese tradition about climate originated in remote antiquity and have been transmitted ever since. Throughout history, more people by far have participated in this tradition than in any other. In China as elsewhere, social memory concerning climate is embedded in both high-level cosmology and local lore. It is a tradition that has sustained a great part of humanity since at least the seventh millennium B.C.

The vast land of China consists of various kinds of terrain, each of which has its own climate. The local cultures, ever since Neolithic times (beginning in the seventh millennium B.C.), each developed their own legends to relate to distinctive climatic conditions. No single tradition of climate legend could be universally applicable to the entirety of China until a dominant culture emerged in the unified empire of the Ch'in-Han period after the third century B.C. Even then, this mainstream of Chinese civilization largely prevailed among the educated elites of the Han-speaking population. Other cultural traditions still survived among ethnic minorities as well as in folk traditions of the Han-speaking population.

Northern Climate

Just to illustrate the variations of attitudes among different traditions, I first present distinctive concerns regarding climate in the north and in the south. The northern part of China, by which I refer mainly to the drainage of the Yellow River, is a loess land. Climate in China is influenced by the monsoon rains from the south in the spring and the frigid air from Mongolia. The monsoon rain is very much reduced by mountain ranges, while dry wind from the northwest brings in arid weather. Hence the Yellow Earth in north China is vulnerable to drought. In these conditions, the northern people have

developed legends concerning the severe effects of drought. For instance, the Yellow Emperor, who is considered a common ancestor of all Chinese, allegedly fought, among many evil adversaries, the Demon of Drought, who appeared as a devilish female named Pa, as recounted in the *Shan-hai-chin* (Classics of mountains and seas). The Yellow Emperor could not overcome Pa even with all his mighty powers until a Ying-Dragon was summoned to subdue her (Hao 1959:9/4, 17/5–7).

A legend of Hou-I also relates to the phenomenon of drought. It is said that in the dynasty of Hsia suddenly ten suns all appeared together, instead of rising one by one over the course of a ten-day cycle. The scorching heat lasted for so many days that food crops were lost and no plant could survive. Answering people's anguished prayers, Hou-I, who was a champion of archers, shot down nine suns, which were in the form of golden crows bursting with fire. Thereafter only one sun appeared each day. For anyone who has been exposed to the merciless heat of north China's summer days, where no shade is within sight on the flat, dry, dusty land, the analogy of ten suns appearing simultaneously is indeed a vivid image.

Throughout the northern provinces of China, even not very long ago, rituals of provoking rain after long droughts were routinely practiced in local communities. The county magistrate had an obligation to preside over such ceremonies in the temples of Dragon Kings (Dore 1966:410–421, 685–693; Hao 1959:14/7, 18/10–11). Even during the days of Mao Tse-tung, peasants in northern communes practiced rain-provoking rituals whenever they were hit by drought, although they risked offending the party commissioners.

Southern Climate

In the south, the role of the dragon is reversed from that in the north. Southern people prayed to the Dragon King more often to subdue floods rather than to provoke rainfall (Karlgren 1946:250–251). The southern provinces, especially in basins and river valleys, always risk flooding because of prolonged monsoon rains and massive precipitation during summer storms. The legend of the great flood therefore is a commonplace theme in southern tradition. In one of those legends, included in the *Shan-hai-chin*, during the reign of Yao, great floods overflowed everywhere. No one could block the inundation until Kun was appointed to control the flood. He stole the wonderful, ever-growing soil called Hsi-jang from the Heavenly God to build banks and dikes.

The theme of the Great Flood is widely distributed among various southern ethnic groups, such as the Miao in the Kwangsi and Hunan area and the mountain Taiwan aborigines. A common story includes an endless downpour of many days that caused floods that, in some legends, only a brother and a sister survived by hiding in a gigantic gourd. The two subsequently became ancestors of the present human population. Numerous researchers have attempted to relate this Chinese flood to the biblical story

of the Great Flood. Such a flood story in southern China need not have been introduced from the Middle East, though, since the climatic conditions in the basins and valleys of southern China provide a sufficient backdrop for such legends to be locally developed.

Ancient Records of Climate

The archaeologically excavated oracle-bone inscriptions of the Shang period (ca. sixteenth to twelfth centuries B.C.) yield information regarding climatic concerns of the Shang people, who resided in north China. The Shang scribes routinely used divination to forecast the weather. The most common inquiries were, "Shall it rain in the next ten days?" "Shall it not rain in the next ten days?" Similar questions about snow and wind were also asked, although less routinely. Of course there is no way for us to verify the accuracy of the forecasts made by the Shang scribes. It is noteworthy, though, that rain was the most important Shang concern. Moreover, in the Shang inscription glossaries many terms distinguish among various kinds of rain (drizzle rain, stormy rain, etc.), kinds of wind (breeze, gentle wind, gust wind, storm, hurricane, etc.), kinds of snow (sleet, frigid, snowy rain, flaky snow, etc.), and varieties of weather conditions (foggy, light cloudy, overcast, shining, dark, and so forth). These rather precise descriptions in the oracle records of the Shang royal court indicate clearly that Shang rulers took account of climate in their daily governance (Chang 1980:34, 144; Keightley 1978:34–36, 43–55, 66, 180–181). Does this mean that the Shang king intended, or was expected, to take measures to change the weather to favorable conditions? The available data are by no means sufficient for us to determine this.

The Chou dynasty (twelfth to third centuries B.C.), which succeeded the Shang, did develop a state cult in which the king, who proclaimed himself the son of heaven, was held responsible for cosmic harmony, including a favorable climatic pattern with the proper amount of rainfall during the planting season and timely changes of the seasons. The Chou king seasonally performed sacred rituals at ceremonial altars to offer sacrifices to heaven, earth, and various cosmic forces on behalf of humanity. This state cult was inherited by Chinese emperors of all dynasties. Visitors in Beijing today still have the opportunity to admire the Heavenly Altar at the domed Temple of Harvest where emperors of the last dynasty religiously performed the imperial duty (Granet 1975:68–80).

Cosmology and Climate Pattern

Throughout the first millennium B.C. a Chinese cosmology gradually took shape. The *I-Ching* (or *Book of Changes*), derived from the practice of divination, organized a theory of yin-yang dualism. Two complementary forces, the yin and the yang, interact dialectically in numerous ways: static versus

dynamic, female versus male, and so on. Climate changes were interpreted in the same manner: seasons rotated as yin-yang alternations. Another system of cosmology is the theory of five agencies, in which five elements or agencies (metal, wood, water, fire, and earth) rotate in sequence to dominate the cosmos, including climates. The origin of this theory is yet to be determined.

At any rate, by the fifth and fourth centuries B.C. these systems had become quite well organized and had gained considerable acceptance. The two sets of cosmology soon merged into an interpretation of cosmic order, which can be called mechanic naturalism. It was endorsed by several ancient thinkers, among whom the best known is Hsun-tzu, an important master of Confucian rationalism of the fourth century B.C. (Schwartz 1985:309–311, 350–380).

The association of environmental changes with the deeds of heroes and the performance of rituals, as well as the recording of climate changes by diviners/priests, may represent social memories of climate that survived from the ancient days when priest-kings exercised shamanistic rituals to influence climate. The cosmology thus is a kind of preserved knowledge or information needed to correct adverse conditions (Gunn and Folan, this volume).

Observation of Weather Changes and Climate

Meanwhile, empirical knowledge of seasonal changes of weather and climates was developed from daily observations. For instance, behaviors of animals were observed in order to mark gradual changes of time. Poems and songs are often full of small bits of such pragmatic observations. The poem "The Seventh Month" in the *Shih-Ching* (or *Book of Poetry*) includes these lines:

> In the Seventh month, the Fire Star passes the Median
> With the Spring days the warmth begins,
> And the Oriole utters its songs.
> In the seventh month the strike is heard;
> In the eight month spinning is begun.
> In the fourth month the small grass is in seed;
> In the fifth the cicada gives out its note.
> In the fifth month the locust moves its legs;
> In the sixth month the spinner sounds it wings,
> In the seventh month in the fields,
> In the eight month under the eaves,
> In the ninth month about the doors;
> In the tenth month the cricket
> Enters under our beds.
>
> (Legge 1960:226)

Similar kinds of observed phenomena were registered in a gentleman-farmers' almanac, called *Ordinance for the Four Peoples*, which lists for each month stages of vegetation growth, climatic changes, and farming activities, together with alleged transformations of various kinds of natural phenom-

ena and the movements of stars and constellations. The precise date of this almanac is yet to be determined; plausibly, it was composed in the fifth century B.C., coincidentally with the beginning of a certain intensification of farming (Hsu 1980:215–228).

Theories of Climate and Weather Changes

By the last quarter of the first millennium B.C., there were three rather separately developed traditions of attitudes toward climate and weather change: first, the responsibility claimed by royal authority, which probably evolved from the dual roles of king and priest; second, a rationalistic interpretation of yin-yang dualism and the theory of five agencies, merged in mechanic naturalism; and, third, the association of observed animal behavior and plant life cycles with seasonal changes of climate. By the time China was unified under the Ch'in-Han Empire, these three traditions were merged into a single theory of interactions between the macrocosmos and the human world. This development probably reflects the appearances of the universal empire and the Confucian cultural universalism of that time.

The traditionally named Theory of Correspondence of Macrocosmos and Microcosmos actually can be described as a theory of unified cosmic order in which the entire cosmos is assumed to have reached a certain equilibrium, with any deviation in any sector of the cosmic order disturbing that equilibrium. Because the human world is one part of the entire system, changes in the natural realm will bring changes in the human realm. Likewise, any human actions, especially those of the ruler or the state (which are supposedly more potent than those of ordinary individuals), will provoke corresponding changes in the natural realm. The usual climatic variations, as well as earthquakes and solar and lunar eclipses, were envisioned as indicators of some disturbance in the equilibrium. In the face of such variations, human behaviors were investigated to see if they might have unbalanced the equilibrium. Individuals or groups were therefore held accountable and responsible for environmental variation.

This theory of cosmic interaction brought three views of climate into a single interpretation. Thus it held that (1) it was the responsibility of the ruler to be a medium between nature and man; (2) there should be an effort to document the correspondence of climate changes to animal behaviors and patterns and to vegetation growth; and (3) there should also be an effort to build up a mechanical scheme to explain changes in nature (Henderson 1984:20–24).

A Cosmic Equilibrium

In ancient times this unified theory was rather attractive. It emerged on the eve of the unification of China. No sooner was the Ch'in-Han Empire established to rule the entire world of China than encyclopedic works, such as the

Lu-shih-chun-chiu and the *Huai-nan-tzu*, were complied to justify the existence of a universal polity rather than the competition of several powers within a multistate order. The final culmination of this theory of cosmic interaction was represented by Tung Chung-shu, a scholar of the second century B.C. Tung argued in his works, of which the best known is the *Chun-chiu-fan-lu*, that irregular changes in climate, movement of celestial bodies (including eclipses), and strange phenomena (including Siamese twins, transfer of gender, etc.) are all omens indicative of misconduct taking place in the human world. For instance, if the emperor had too many female companions in his harem or if he bestowed unusual favors on the relatives of such ladies, he then had received excessive levels of female influence. Excessive yin (female) influence in the human world would be reflected, say, in too much rain, as the water represented the female elements of the yin-yang dualism. By the same reasoning, Tung might point out that excessive penalties on criminals or numerous executions would provoke harsh, severe weather in the fall. The concept of punishment and the concept of autumn were both related to the agency of metals in the five agencies theorem (Hsiao 1979:503–525).

These interpretations, based on assumed correlations and associations among otherwise independent sets of phenomena, opened two possible ways to make corrections that would repair and restore a disturbed equilibrium. One option was witchcraft. Tung included in his work recommendations of this kind. For example, to guarantee a mild spring with sufficient yet not excessive rainfall, a green-colored dragon made of earth should be placed in the east of the city, because green, east, and spring were all related as one category of conception in the five agencies theorem, while the dragon of course was related to rainfall (Loewe 1994:142–153). This association of symbolism has actually survived to our time. A farmers' almanac is published each year in Hong Kong and in Taiwan. The first pages usually include a picture of either a spring dragon, or a spring buffalo, with detailed particulars as to its size, shape, the direction it faces, etc., both as instruction to perform acts necessary to bring favorable weather and as a forecast of precipitation during the farming season in the region where the almanac is being published. No one, however, bothers to find out who makes the forecast or how the prediction turns out.

Another way to correct an already-disturbed equilibrium was to impeach the wrongdoers whose mischievous conduct had presumably brought on the deviation from normal equilibrium. Throughout the Han dynasty, prime ministers were routinely accused of being responsible for solar eclipses, meteorites, droughts, floods, epidemics, and so on. Emperors were sometimes impeached by courageous scholars, who submitted memorials to remind the court that some unusual phenomenon had occurred and that the imperial authority should be held accountable for the wrongs and errors that caused it. Even dynastic changes were made on the pretext of such impeachment (Loewe 1994:88–97; Henderson 1984:24–28). After all, if peo-

ple had such beliefs, public opinion could be fanned to such a level as to be irresistible.

Belief in the political implications of changes in the natural order remained a part of Chinese life for a very long time, although the particular school of thought advocated by Tung Chung-shu gradually faded after the second century A.D. Nevertheless, for almost another millennium, official dynastic histories usually would reserve a special chapter to record unusual phenomena that were considered omens. Most of these records relate to climate. Severe, prolonged cold or heat, long-lasting rainy seasons, the early arrival of frost or snow, unseasonably warm or chilly weather, drought, frequent hurricanes, early flowering of certain plants, early departures of migratory birds, and many other phenomena were recorded.

Use of Climatic Records in History

These records from official histories actually can be quite useful to the modern scholar, because they cite precise times and localities. In Chinese history there are at least two periods during which massive migrations were triggered by prolonged, dramatic changes. The forefathers of the Chou dynasty, before they moved south into the Wei River valley, in the fifteenth to fourteenth centuries B.C., seemed to have been pressed by other peoples from the north. This was also a time of massive movements of peoples across the Eurasian continent, such as the migrations of Indo-Europeans to India (Hsu and Linduff 1988:50–54). Another case is the long period of wave after wave of northern ethnic groups moving into China, while the Han Chinese in turn moved south during the third to late sixth centuries A.D. I have used official records to create three charts depicting observations of cold weather from the late first through late sixth centuries A.D. (fig. 8.1). One chart is based on records of the northern dynasties, and the other two on southern records. These tables reveal two parallel curves of cold weather. The southern curve shows milder and shorter periods of cold weather than the northern one (Hsu and Sun 1987:243). My investigation thus suggests that a general trend of prolonged coldness in China during the period in question prompted the migrations from the northern Asian steppe into China proper. Such a series of events is by no means unique to China. Some scholars believe that climatic change may have helped cause massive migrations that, in some cases, brought about the collapse of complex societies.

Calendar Making and Weather Patterns

The theorem of cosmic interaction, as we can see today, does not stand up to serious tests and questions by the standards of analytical science. In the past, however, if weather patterns were noted to be abnormal, there had to be a

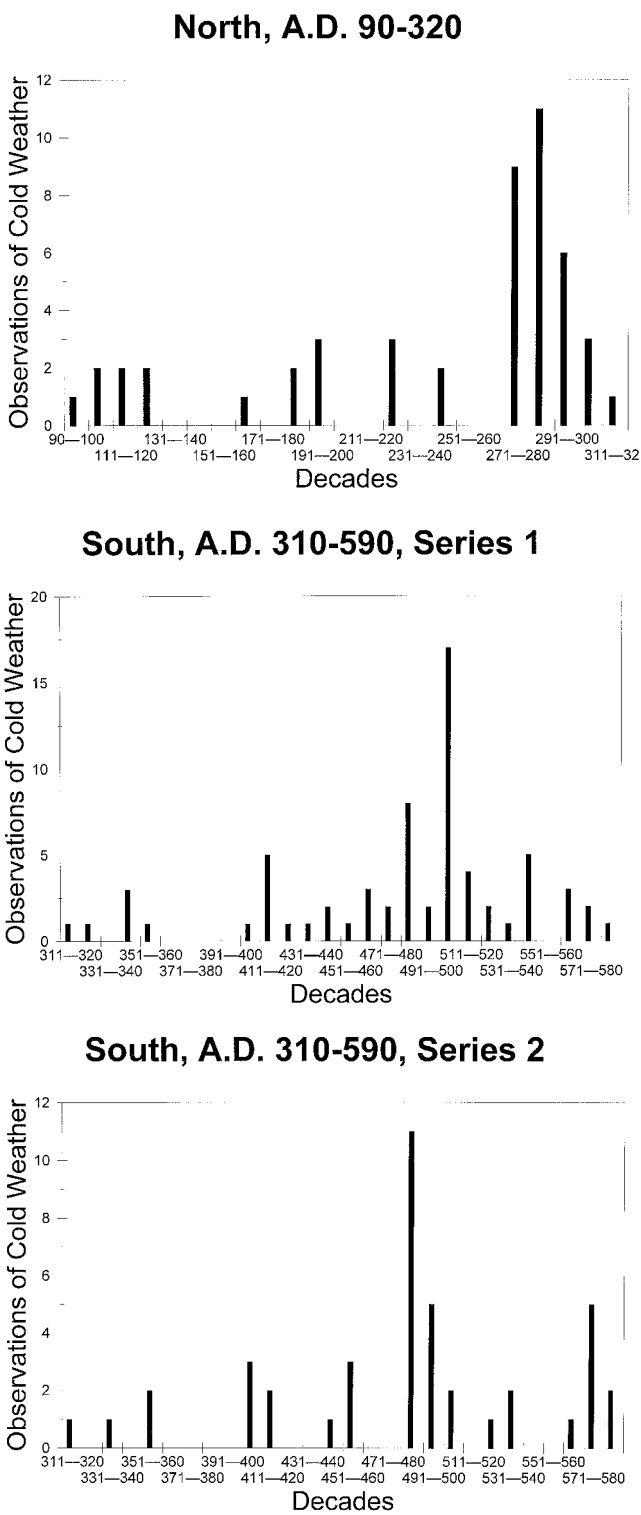

Figure 8.1. Observations of cold weather in Chinese dynastic histories, A.D. 90 to 590.

moral explanation. The ancient Chinese thus made great efforts to identify weather patterns and explain them.

Calendar making was always an important task in ancient China. It can be viewed as an application of social memory in that it related physical nature with social behavior (Dean, this volume). In a land of farms with clear seasons, monsoon rains, and Siberian low pressure, it is crucial for farmers to know when an agricultural year will start, when spring rains will arrive, and when the soil will freeze. Divination records make it clear that the Shang people of the sixteenth to twelfth centuries B.C. had developed a solar-lunar calendar. The solar year had 365 days, while the lunar months had 29 or 30 days. An interpolated month was added every three years, five years, nine years, and so on to make a year of four seasons, normally consisting of twelve (or thirteen) months, each of which had the full moon on its fifteenth (or sixteenth) night. Dates marked climate changes, including the winter and summer solstices, spring and autumn equinoxes, and others. The solar year was divided into twenty-four intervals. In order to check the precision of the calendar, the astronomers observed solar eclipses taking place on the last day of a month and lunar eclipses on the fifteenth night. The precise days of solstices were determined by measuring the length of a shadow every day until the right moment was marked.

We do not know how early this simple astronomical calculation was practiced. The Shang calendar, however, seems to have been rather accurate, and it appears to have been incorporated into later calendars with relatively minor revisions. In Chinese history, there has been no interruption in continuity of calendars; nothing resembling the abrupt change between the Julian and the Gregorian calendars occurred in China's past. Careful calendar making is a long tradition in China. Chinese astronomy was its byproduct; even Chinese mathematics was its byproduct. Thus serious concerns to determine climatic regularity unexpectedly reaped a harvest in the development of the sciences.

Concepts Relating to Temporal and Spatial Influences on Human Life

Calendar making in China until the seventh century A.D. always involved a calculation of the lengths of many cycles: the lunar cycle (month), the solar cycle (year), the combined cycle of these two, the cycle of sixty days (which is a way of counting dates), the cycle of sixty years (which is a way to count years by using the same ordinal signs as the sixty-day cycle), and a grand cycle that combined all lesser cycles (beginning at midnight on the first month of the first year of the sixty-year cycle). The grand cycle starts an epoch, roughly a period of a half-million years. This manner of counting time, which Joseph Needham called *dirthmatical*, originated from the need to comprehend seasonal climate changes. It affected Chinese perspectives of continuity and

change as well as progress and return, a dialectical and cyclical view that is distinctive from the Newtonian evolutionary-linear perspective that still prevails in Euro-American peoples' minds today (Needham 1954:229). A Chinese today can easily envision that, whatever changes are taking place, everything will come back along a pendulum path sooner or later and anything that goes to extremes, or even just becomes excessive, will return to its middle ground after a few swings of that same pendulum.

On the spatial side, Chinese have long had environmental concerns about the selection of sites for settlements and tombs. Any locality is related to its surrounding terrain, that is, the landscape. This relationship maximizes the benefits of climate. This practice of geomancy is known as *fen-sui*, or "wind [and] water." It is a filter of past experiences, from which observations are summarized into a few patterns (Loewe 1994:66–67, 80, 191 ff.; see McIntosh, this volume).

China is a vast country that has always had problems feeding its large population. Chinese farming has thus been intensive for a long time. It is, however, virtually like gardening (see Crumley, this volume). From the day of the first tilling of the field in early spring right after the soil has thawed, through the preparation of the ground, sowing, and field management (such as weeding), to the final harvest of the crop, every step requires careful timing in order to maximize productivity. Crop rotation and the storage and preservation of harvests also depend on timing. A little too much water in the rice paddy or a little insufficiency can make the difference between a good harvest and failure. Harvesting ripened millet a few hours before the first wind blows it away means reaping the benefit of the whole crop. Being right on time to break the almost-thawed ground may ensure that moisture is kept in the soil; one day too late for a second tilling may cause the exposed soil to be hardened by the wind (Hsu 1980:280–282).

Therefore farmers (who make up about 80 percent of the population) have summarized time-proven experiences into proverbs that predict weather changes. For instance, evening sunlight after a whole day of clouds is a sign of more adverse weather on the way. A yellow halo encircling the moon means a strong wind the next morning. Ants massively moving away from their home indicates that heavy rain is going to fall. A fine day on the winter solstice predicts a warm winter of little snow, which is not good for the spring crop. A crop of sweet fruits one year will be followed the next year by a crop of diluted sweetness. Three years of good weather will be followed by a terrible fourth year. Crops surfacing in a pond indicate an imminent storm. Visible breath from water buffalo signals the early arrival of spring, which may coincide with widespread epidemics. Less snow on the ground in winter means more insects in spring. Thousands of such proverbs are encountered in daily conversations in the countryside. Thus we say that our food is a gift of weather and that human effort contributes 10 percent, while nature takes care of the rest. A cardinal principle for farming is given in a farming handbook compiled in the second century A.D.: "Be timely!" (Hsu 1980:280).

In summary, Chinese attitudes toward weather result from an intimate relationship between observation and interaction. Human effort is vital to weather, whether it be sorcery performed by a priest-king, a corrective policy recommended by a Confucian minister when a wrongdoing emperor is impeached, a ceremony of praying for good harvest that associates an earthen dragon with proper rainfall, an effort by astronomers to design a calendar with high accuracy, or a farmer's immediate response to a weather change while his mind is influenced by proverbs of pragmatic wisdom. Whichever attitude or action is appropriate, the constant point is that nature reveals changes of weather and climate, and human effort takes action accordingly. This is the lesson conveyed by millennia of Chinese social memory.

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Part 3

Cultural Responses to Climate Change

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Chapter 9

Three Rivers: Subregional Variations in Earth System Impacts in the Southwestern Maya Lowlands (Candelaria, Usumacinta, and Champotón Watersheds)

Joel D. Gunn and William J. Folan

The Earth System and Archaeological Practice: A Question of Reconciliation

How can archaeological practices and new understandings of the earth system meet in productive interaction? Since 1958 a vast and growing array of sensors has been deployed in the oceans, atmosphere, and space. From them comes a flood of data from the earth system into the data archives of United Nations organizations and national climate programs.[1] These observations have vastly supplemented scientific knowledge of the earth system and overturned existing preconceptions of its form and structure. As a result, diverse concepts of earth system organization have emerged, among them that of biochemist Lovelock (1979), oceanographer Broecker (Broecker and Denton 1990; Broecker 1995), and Dunbar in this volume. They, and many others, document the ongoing revolution in conceptualization of global climate precipitated by this observation feast. From knowledge emerges a picture of intricately interwoven atmospheric circulation, ocean circulation, heat storage and dissipation, and astronomical and geophysical influences that force changes in heat storage. Because the oceans store heat for periods of years, and the atmosphere has only a brief, one-month heat memory, the oceans are major players in long-term atmospheric conditions. The atmosphere likewise responds to short-term disturbances such as volcanic eruptions and changes in solar emissions. Always adjusting to a variety of external influences, the atmosphere is the short-term sensor, or carrier, of the total state of the system. The well-watered lower atmosphere, in particular, is the life envelope within which nestles biological activity and the record of its

evolution. In this chapter we will attempt to show how the vast new reservoir of knowledge concerning the earth system can be applied to long-term changes when they are imposed by variations in worldwide parameters. The Maya lowlands will provide an example.

The broader outlines of earth system organization were legitimately the initial focus of conceptual efforts by the scientific community through the 1970s and 1980s. It is becoming increasingly and perhaps belatedly clear, however, that the critical issue for terrestrial biological life forms—including humans—is the impact of earth system changes on regional climates and local biocultural systems. For us, *bioculture* means the regional-scale interaction of biological organisms and cultural organizations with climate and geology, as well as with the residue of that interaction, soil. Because of the stratification of soil sediments, they contain the history or trace of regional interactions (a dramatic example is soils in the Mediterranean basin, which were thoroughly reworked during the Roman Empire [Butzer 1982]). The techniques of archaeology are clearly an avenue through which to investigate past changes in local systems. Thus, by looking at the Maya, we will attempt to sharpen our understanding of long-term global change and local impacts detectable in local biocultures.

How do global-scale earth system phenomena affect local conditions? Digesting new information on the earth system in a manner that is useful for archaeologists and other regional scientists (hydrologists, geologists, social scientists, historians, biologists) is not always easy or straightforward. This is especially so in efforts to use the concepts of branches of science that emphasize the physical aspects of the earth system without regard for involved social and biological subsystems. Yet the discovery of a complex and potentially confusing climatic interaction between biocultures and the earth system poses a difficult but unavoidable problem for students of local conditions. In the past decade we have made a concerted effort to study the impact of global change on local communities and landscapes. The following overview is distilled from technical publications (Folan, Josserand, and Hopkins 1983; Gunn 1991, 1997; Gunn and Adams 1981; Gunn and Grzymala-Busse 1994; Gunn, Folan, and Robichaux 1994, 1995; for further nontechnical discussion, see Gunn 1994c).

To understand the past and future of biocultures requires, in addition to direct observation of biocultural soil traces, a conceptual grasp of global processes. It is not useful for study of the past simply to suppose that the climate system is too variable for generalizations, which some but not all physical scientists do (see Dunbar, this volume). While it is true that there are freely varying components of the atmosphere-ocean system, it is also clear that past variations involve quasi-deterministic processes. These include the changing tilt of the earth's rotation axis toward or away from the sun (precession), which varies over thousands of years, and variations in solar emissions over both decades and centuries. Properly conceptualized and applied, these regular process-generated variations assist in the search for pattern amid the rubble of time (Gunn 1997; Gunn, Folan, and Robichaux 1994, 1995). If non-

scientists, from simple organisms to nonindustrial cultures, have some capacity to plan for earth system variations—if, for example, trees and farmers can understand some part of the global-regional climate system for their life-planning purposes[2]—can regional scientists understand it well enough to plan for anticipated global-scale changes or to unravel the mysteries of the archaeological past? This is not a trivial question. Folk cultures and trees have had millions of years to work on the problem, scientists only decades.

This chapter explores subregional variations of the impact of earth system change on atmospheric circulation and related changes in seasonal precipitation. The amount of water available to humans is the key controlling factor in population density and a number of other biocultural parameters. More importantly, the distribution of water over the seasons controls biological productivity and human population. We have found that the monthly discharge of rivers is the simplest and most reliable measurement of both quantity and distribution of water. The region of study is therefore three watersheds in the southwestern Maya lowlands (fig. 9.1).

At a much broader scale we have found that rivers are highly variable in their responses to global temperatures. A decade of iterative investigations of watershed discharge around the North Atlantic basin has shown that

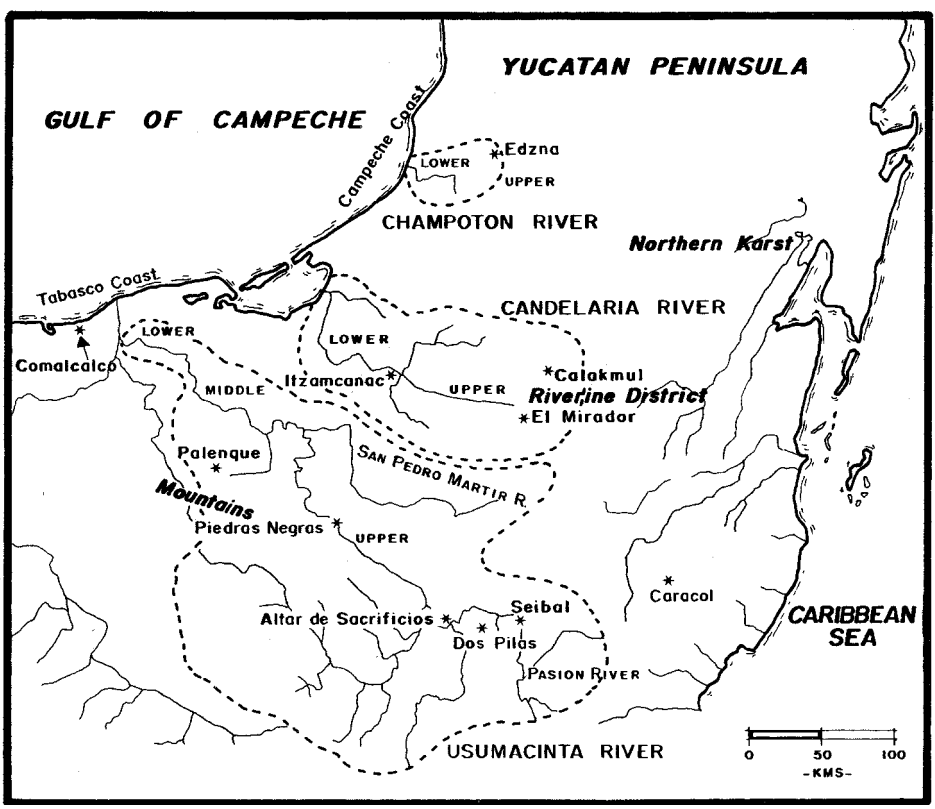

Figure 9.1. Map of the southwestern Maya lowlands showing Champotón, Candelaria, and Usumacinta watersheds.

some rivers, such as the Candelaria River in Campeche, Mexico (Gunn, Folan, and Robichaux 1994, 1995), and the Mechet Creek in Burgundy, France (Gunn and Crumley 1991), respond strongly to changes in atmospheric temperatures. Other rivers such as the Usumacinta River of the Sierra Madre Oriental in Middle America and the Sabine River of Texas-Louisiana, follow global temperatures not at all. In this study, we enrich our understanding of the regional impacts of global change by analyzing discharges from multiple adjacent watersheds in the same region. The investigations show that hydrological variability relative to global change is strongly affected by subregional conditions. Can these variations be harnessed for archaeological interpretation of cultural activity? Or, alternatively, is interpretation of archaeological sites possible without understanding them?

Our analysis suggests that the three adjacent watersheds we studied, even though they are closely spaced, differ substantially in their responses to a suite of direct and indirect effects, including global temperature, proximity to ecotones, local topography, geology, and human modifications. Taken together, the response patterns of the combined Champotón, Candelaria, and Usumacinta river watersheds form a regional response surface, a mosaic of conditions that influence and are influenced by subregional bioculture. This bioculture includes the environmentally highly assertive three-thousand-year-old Maya culture.

To give our study the broader perspective of deep time, we incorporated the whole of Maya history, investigating the interactions of ancient Maya lowland city-states within this global-local hydrological mosaic. We found that local human cultures temper the effects of global climate change and consequent regional moisture changes on themselves through dynamic, region-specific techniques, including crop-planting strategies that are sensitive to interannual variations in climate. The range of these strategies in a region represents the cultural memory of the regional culture (Gunn 1994a). Some of the subregional climate variations appear to account for some aspects of shifting political power in the Maya lowlands during their period of high civilization in the first millennium A.D. A comparison of intraregional cultural chronologies of the southwestern Maya lowlands with the differing response processes of their three rivers' environments suggests these processes may have been contributing factors to episodes of subregional cultural change and stability. Thus, from the local farmer in his/her habitat to the vast oceans and atmosphere of the earth system, there is a thread of interaction that sustains all.

The Earth System and Archaeology: Assimilating Global-Regional Theory and Method

Since the 1970s, scientists have become increasingly comfortable with the concept advanced by Budyko, Lovelock, and others that sees the earth system as a biological superorganism that controls its temperature at favorable

levels for life. As Budyko (1980) notes, without this control the average earth temperatures would be –18°C. Untold energy has been poured into gathering information on atmosphere and oceans, some of it derived from international space programs. We might note as well that similar great effort has been poured into gathering information on past cultural systems through a worldwide network of historical preservation programs. Concepts of past cultures have probably changed as much in the last thirty years as have ideas of the earth system. The two massive data sets await reconciliation.

From the theoretical perspective of Western science, the three major components of the earth system are atmosphere, ocean, and culture. There are, however, significant conceptual gaps between models of these components, because they were developed in the relative isolation of disciplinary research in the years following World War II. It seems necessary and desirable to establish bridgeheads (fig. 9.2) at the edges of climatology, oceanography, and anthropology to link the decidedly different disciplinary perspectives and methodologies into a working whole, a conceptual and technical tool to investigate the earth system, inclusive of humans and their biological cotravelers. The paradigm of global ecology has been emerging since the 1970s (see Budyko 1974, 1980; Lovelock 1979, 1988; McMenamin and McMenamin 1994; see also Goldsmith 1988 for a review of an integrated pre–World War II ecology). At the heart of this structuring has been the question of how to salvage essential parts of the old disciplines, especially their key concepts, without continuing the fragmented disciplinary baggage of the

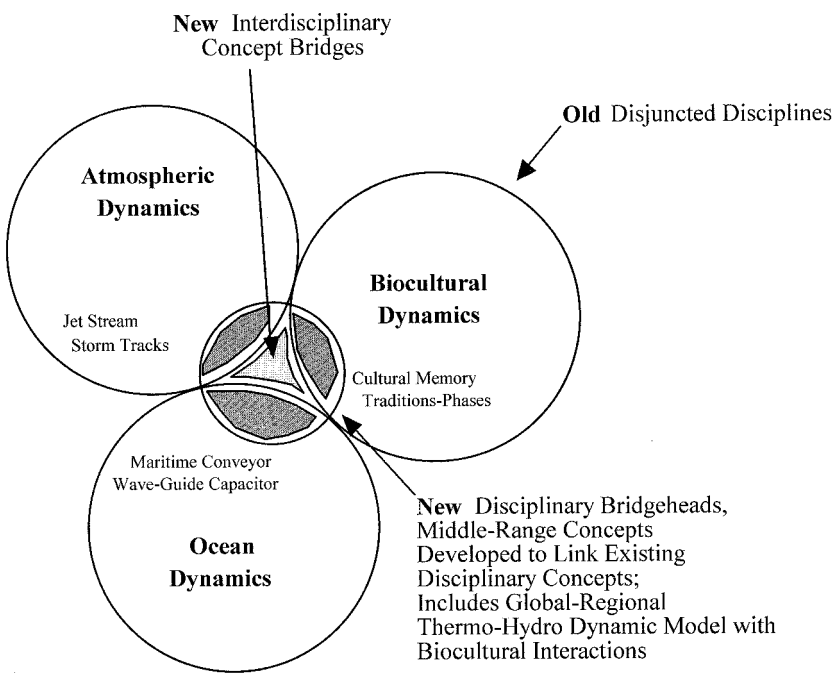

Figure 9.2. Middle-range concepts at the interdisciplinary triple point linking the dynamics of atmosphere, oceans, and culture.

post–World War II era. Furthermore, the bridgeheads must facilitate a constant traffic in new findings from deep within the existing disciplines to forestall stagnation in disciplinary interactions. How are we to contrive a mental workspace in which productive theories can generate new hypotheses and new perspectives on physical and social phenomena?

Part of the answer lies in a body of thought called "middle-range theory." Middle-range concepts were used in sociology in the 1940s to show relationships between broad principles and specific social characteristics. In a narrow methodological sense, middle-range concepts are a set of techniques that view research as being informed by concept but grounded in empirical observation. Middle-range theory, or perhaps concepts (Winterhalder 1994), has its utility in bridging broad ideas such as "culture" and more immediate situations, such as archaeological sites or a specific culture that an anthropologist is studying. Extensive archaeological literature exists on the topic (Raab and Goodyear 1984; Carr 1989). Middle-range concepts are frequently bridging mechanisms between culture and environment. Usually under the guise of site formation processes, middle-range concepts link naturally enough to the earth system concept.

In the culture-climate debate, middle-range concepts could be developed as bridges between sister disciplines and their respective grand theories (see fig. 9.2) should and could be addressed. Such bridges should draw on the essential qualities of the old disciplinary concepts, such as atmospheric and oceanic thermodynamics and culture change, integrating them into a working whole properly scaled for a global-regional research orientation. The utility of such a process is that it undergirds the overarching global ecology paradigm with long traditions of experience. The year 1997 marked the two hundredth anniversary of publication in archaeology on the question of culture and global climate change, although in 1797 John Frere probably did not understand that the antediluvian controversy would eventually evolve into Pleistocene studies (Gunn n.d.a). Similar durations of interest can be traced in astronomical climatology and geology (Schneider and Londer 1984:260).

As an example, a simple bridge between global climate and culture change can be made by measuring the potential familiarity of a culture with a region's climates—its cultural climate memory—through the range of global average temperature oscillations during the culture's tenure in a location (Gunn 1994a). For Egyptians (Hassan, this volume), whose culture has been in place for thousands of years, the cultural climate memory is as broad as Holocene global temperature variation. For the Navajos of the southwestern United States, who only migrated to the area in the A.D. 1400s, cultural climate memory is much more limited.

Such engines integrating climate and culture change could benefit any number of studies. Two examples that link atmospheric and social processes could be to use an externally forced data model or general circulation model outcome to examine the range of adaptability of cultures to regions depend-

ing on their time in place in a region. Turning the game around, one could use cultural histories to test the effectiveness of the data model or general circulation model outcome to provide retrospective understanding of global climate boundary conditions for cultures, such as those resulting from changes in insolation because of varying orbital tilt (see Davis and Sellers 1994; Kutzbach and Guetter 1986: Gunn and Crumley 1991).

The first element of a methodology linking the vast archaeological and paleoenvironmental database for understanding culture-climate interaction is a comparative tool measuring past climates against current instrumental records. Two articles in the literature presenting scenario-based or analogic methods for estimating the effects of global temperature change are helpful in this regard (Sanchez and Kutzbach 1974; Wigley, Jones, and Kelly 1980). Our interest in global climate was initially piqued by Sanchez and Kutzbach's (1974) use of the globally cool decade of the 1960s as an analog to estimate the impact of the little ice ages on moisture. The study showed that during cooler global conditions, the westerly storm tracks that cross the Americas shifted south, redistributing precipitation in their wake.

In an effort to link atmosphere and local culture changes, we joined forces with a colleague specialist in Mesoamerican civilization. Our articles (Gunn and Adams 1981; Folan, Josserand, and Hopkins 1983) focused on the cyclical florescence of civilizations in the Maya lowlands and highland Mesoamerica but included discussions of related periods in the U.S. Midwest, Africa, and Europe. It showed intimations of relationships during the last three thousand years between the magnitude of cultural activity, particularly in global zonal ecotones (tropics, subtropics, temperate, and polar), and global temperature as measured by the extent of polar glaciers (Denton and Karlen 1973). For example, in northern Mexico, where there are only deserts and ruins now, an equatorial-subtropical ecotone, cities flourished in the Medieval Maximum (A.D. 900–1250), which was globally warmer than the present. We suppose that warmer global conditions extended tropical moisture poleward from the equator. This extended moisture overran formerly dry subtropical lands, allowing them to support large populations and ambitious urban construction programs. Folan (1981, 1984; Folan et al. 1983; Folan, Josserand, and Hopkins 1983) discusses several implications of this model specific to the Maya lowlands for settlement patterns, linguistics, and population movements.

Following these initial insights, the underlying focus of our climate work has been on global temperature changes that shift storm tracks and thereby regional moisture. The Sanchez and Kutzbach findings (1974) were reinforced by Angell and Korshover's (1977) discovery that storm tracks (the north "circumpolar vortex" in their language) expand, or shift south, with cooler global temperatures. Precipitation tends to occur at the edge of the circumpolar vortex, where the polar air mass meets the equatorial air mass. This is typically seen in weather satellite images as fronts. Refinements of global-local models can be made for regional conditions using more

restricted atmospheric features such as the Bermuda-Azores subtropical high (Folan et al. 1983; Gill 1994; Gunn and Crumley 1991; Crumley and Gunn 1997).

Thus the utility of the global average temperature is that it is the key variable in atmospheric thermodynamics. It offers manageable access to the processes of the earth system at any timescale for which atmospheric temperature data can be obtained. These scales range from hour-by-hour instrumental observations in the twentieth century to paleoenvironmental decade, century, and millennial scales in history and prehistory. It includes global circulation model projection scenarios for future global warming and theoretical prognostication of future ice ages based on precession.

If one is specifically concerned with the dynamics of atmospheric temperature variation, instrumental observations can be used as analogs for past conditions (Gunn and Crumley 1991; Gunn, Folan, and Robichaux 1994, 1995). In effect, the earth system becomes an analog simulator of a global climate model; the data are tapped off at whatever sampling interval is appropriate for a study. The senior author has referred to this as the "Big Computer" method; the Big Computer simulates the world climate year after year and gets it right (Gunn 1994b). Wigley, Jones and Kelly (1980) have used annual global average temperatures in a similar fashion to estimate the effects of increasing global trace gases on atmospheric temperatures.

As useful as climatologists' and oceanographers' perspectives are, they continue to look down on local environments from afar and at broad scales of many tens or hundreds of kilometers. Climate change from the perspective of a regional bioculture looks up; the global climate poses incoming problems or benefits for local communities. To build a looking-up scenario, it is necessary to join the dynamics of the greater earth system to a pinpoint of local geology, soils, biota, and culture of the local bioculture. Archaeologists generally deal with sites; however, a tree is a striking, emblematic example of the smallest subregion: it takes the donations of the atmosphere, mixes them with the geological endowments of its location, weathers the influences of biological and cultural organisms, and therefrom creates an annual record of its solutions to climate-geology-bioculture problems in its space and lifetime. Regional biocultures perform similar alchemy at a larger scale, leaving their record in the soil; a less resolved record than the tree, to be certain, but nevertheless a record.

In several projects we have suggested that the local record can be modeled and simulated by correlating subregional-scale river discharge volumes with tropospheric temperatures.[3] Discharge volume is a broad-based indicator of local moisture conditions. Tropospheric temperature above five thousand feet is a broad-based indicator of atmospheric status undisturbed by local anomalies. Modeling global-regional processes by correlating tropospheric temperature to watershed discharge appears to be effective for several reasons that are discussed below. The model-building process is limited to the period since 1958 (the period of intensive instrumental observa-

tion or PIIO), because during the International Geophysical Year (1957–1958) worldwide standards were implemented for accurately measuring temperature of the atmosphere. The troposphere is the short-term carrier wave of the earth system's thermodynamic status. Simultaneously, it is the key link between hydrological reservoirs (oceans, the long-term carrier) and human-occupied land surfaces (regions). To rephrase Meggers's (1979) position, variations in the carrier constrain the human potential to occupy and flourish in a region.

We have proposed that externally forced—that is, earth system—variables can be used to model past discharge from present-day measurements. At least three reasons explain why past hydrologies can be projected from present-day watershed discharge variation and external forcing data. The reasons can be formulated as three hypotheses: rehearsal, projection, and variability.

Rehearsal

This method detects global impacts more effectively at the edges, or ecotones, of ecological zones (fig. 9.3) than toward their centers. For example, in east Texas there is little global response in the Sabine River, which is located in the southeastern United States ecozone, but the Pedernales and Frio rivers farther west on the prairie-forest ecotone are very responsive to tropospheric average temperatures in complex and powerful ways (Gunn 1979; Gunn, Folan, and Robichaux 1995). We suggest that from the point of view of cultures, ecotones amplify shifts of lesser variations in tropospheric temperature. Culturally diverse populations that dwell on ecotones record their adaptations in cultural memory; these adaptations are in effect rehearsals for successful colonization of the ecozone should greater changes in the tropospheric temperature unfold, overriding the ecozone's internal stability.

The rehearsal hypothesis for ecotonal regions illuminates one of the great truisms of anthropological studies: humans are creatures of the ecotones. Human evolution in fact could be argued as a series of genetic steps or radiations; at each step, the ecotonal variant of the hominid species was genetically extruded through ecotones (for examples, see Jolly and Plog 1987:190–228, 267–290; Campbell 1976:156, 163). The mixture of seeds and

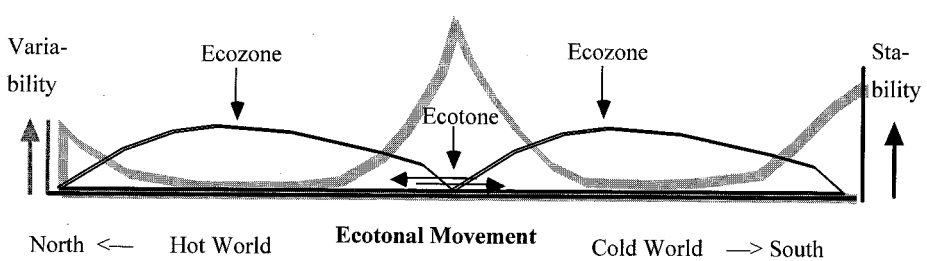

Figure 9.3. Variability, stability, and ecotone movement relative to global temperatures.

fruits on the forest-savanna ecotone shaped the characteristic mixed human dentition in its earliest stages. The concept has been extended to the southeastern United States in Steponaitis's (1978) analysis of Mississippian settlement systems and the advent of Roman political power in eastern France (Crumley 1993). The ecotone rehearsal hypothesis probably also explains why humans in their near-present physiological status appeared at the beginning of the Pleistocene (*Homo habilis*). The Pleistocene is thought to be an epoch of great environmental variability, compared to the less variable earlier epochs of the Cenozoic. Humans, then, represent a solution to the questions of how primates adapt to highly variable conditions. Similar adaptive strategies can be seen in other primates, such as the highly successful baboons.

Even if other parts of the ecozone-ecotone system are not responsive at ordinary levels of variation, the variation of the ecotone and the habits humans build around such conditions are a key element of the human adaptive methodology for long-term climate change. As Wissler (Freed and Freed 1983) proposed early in this century, innovation appears to emerge from peripheral situations and spread to centers. The ecotones, then, are cultural-diversity generators and reservoirs. On them cultural traits await implementation when global climate change forces notable changes deep in the ecozone. The southwestern Maya lowlands discussed later present a superlative example of the rehearsal hypothesis.

Projection

A second reason that the analysis of ecotonal rivers is useful to estimate regional effects is that if there is a regional trend in the tropospheric average temperature, then that trend can be projected from the current ecotonal response toward a broader range than that apparent during the PIIO. For example, in the Candelaria River watershed, there is a tendency for the length of the dry season to adjust with changes in tropospheric average temperature (Gunn, Folan, and Robichaux 1994, 1995). Under PIIO conditions, it is seldom the case that the dry season is completely erased by warmer tropospheric temperatures and consequent northward expansion of the tropical zone (see fig. 9.3). Enough of a trend is present, however, for the tropospheric average temperature at which the dry season disappears to be projected to greater than currently observed changes. Cautions are appropriate as with all forecasts: such trends are not a property of the variation; they are a property of the model. This is especially true if atmosphere is a nonlinear complex system with stepwise changes in states (Gunn 1997). The disappearance of the dry season in April, however, is a profound threshold in our model of the condition under which upland crop productivity falls from high (a regime of mixed dry-wet seasons) to low (year-round tropical conditions) (Faust 1998:143; Folan and Gallegos 1992; Folan and Gallegos Osuna 1998; Gunn, Folan, and Robichaux 1994, 1995); this change will gen-

erate a stepwise change in the culture whether the atmospheric system changes continuously or stepwise.

Understanding and applying this projected climate hypothesis, both its potentials and limitations, is critical to forecasting future climatic conditions and subregional biological, agricultural, and industrial productivity. (Recall that industrial production is often if not usually dependent on huge amounts of water.)

Variability

Too often our efforts to conceptualize past climates are seriously constrained by the preconceptions imposed on us by the climate experienced in our lifetimes. We recognize that there were past conditions for which there is no existing parallel, such as during the Pleistocene Ice Age. Upper Paleolithic cave painters are thought to have lived in a subarctic tundra so rich in biomass that we can only guess at its wealth. Other vastly different conditions probably lurk unrecognized in the Holocene, when global temperature extremes appeared (Gunn 1997).

While it is true that paleoclimatic research findings suggest conditions for which there are no apparent analogs in the instrumental record, the question of analogs is not the whole of the global climate. The weather of any given month can contain weather variations reminiscent of most, or perhaps any, past condition, be it Ice Age cold or Holocene hot. For this reason alone, the emerging emphasis in climatology on variability noted by Dunbar (in this volume) is to be applauded. Observed variations of ocean heat storage (El Niño), solar emissions, frequency of volcanoes, and encounters with meteors can force variability in weather across the spectrum of atmospheric temperatures between Gaian boundaries. (By Gaian boundaries we mean the extremes that the earth system can tolerate without major instantaneous extinctions of life forms and occasionally, usually every few million years, including mass extinctions.)

How do we make use of this modern variability to understand past—or future—conditions? Although the veracity of our global-local climate functions derived from global temperatures and river discharge has been questioned, we have positive results to report. We have simply used the observation made by atmospheric scientists at the beginning of many articles, that seasonal variation exceeds climate variation (see Schneider 1987 for an example). Why is it that the last three thousand years of Candelaria discharge can be simulated with convincing accuracy by a model developed from 1958–1990 variability? Why does a similar model developed from Mechet Creek discharge in Burgundy project reasonable estimates of discharge for the latest Pleistocene (ten to fourteen thousand years ago, really the Pre-Holocene)? The only apparent answer is that a range of variation in the modern data is equivalent to that encompassed by near-Pleistocene weather conditions. Thus there is more in the PIIO data than the current

global climate, the averages of the PIIO; there is also variability that can be stretched to simulate past extreme climates. Can these alternative scenarios of past conditions be re-created within the range of variation of the PIIO? The evidence minimally suggests that this variability hypothesis should be investigated. In addition to the positive findings already cited, however, there are problems to be resolved; as will be discussed later, the method does not appear to predict extreme Usumacinta discharge lows during globally cold periods.

The Earth System and the Maya Lowlands

As Columbus sailed along the Caribbean coasts, he encountered large ocean-going canoes laden with trade goods. They were bound for distant ports around the Yucatan Peninsula and adjacent Vera Cruz and Honduras. The Maya-speaking people who propelled those canoes had begun their international trading life three thousand years earlier, during riverine encounters between interior crocodile-hunting villagers and sophisticated Olmec traders from the Tabasco lowland. The Olmec traders were probably searching as much for river passages to shorten trade routes as to extend the reach of their trading empire into the Yucatan. As the Maya villages lie along crucial riverine passages through the Yucatan Peninsula, the intervening millennia between Olmec traders and Spanish sightings were filled with vast reaches of civilized accomplishment that propelled the Maya beyond their trading partners in matters of astronomy, architecture, art, mathematics, and writing. The Maya built great cities at positions of power and control along their interior trade routes.

In the foregoing section of this chapter we built a perspective on the earth system that facilitates detection of disturbances in the global environment within subregional biocultures. In the following section we attempt to lay the history of the Maya against their landscape and its susceptibilities to global change. Amid all the other complex activities of the Maya cultural life, we hope to find a signal attributable to disturbances in the oceans and atmosphere. (David Freidel discusses the rich social context of the Maya in his chapter of this volume.)

Landscape Analysis of the Southwestern Maya Lowlands

We studied the landscape constituents (geology, atmosphere, hydrology, biota, and culture) of the southwestern Maya lowlands during research on the Candelaria watershed (Gunn, Folan, and Robichaux 1994, 1995). Reviewing that landscape in the following paragraphs will lay a foundation for study of the Usumacinta River to the south of the Candelaria River and the Champotón River to the north (see fig. 9.1).

The Candelaria watershed lies within a one-hundred-fifty-kilometer-wide (approximately ninety miles) east-west band across the southern Yucatan Peninsula; we will refer to this as the "riverine district" (see fig. 9.1). Since the Yucatan Peninsula is a platform composed of sedimentary limestone and dolomite, and the Sierra Madre Mountains are metamorphic and uplifted (Aliphat Fernandez 1994), these two physiographic provinces are markedly different in bedrock characteristics and bedrock-related hydrology. To the north, the Yucatan Peninsula is a honeycombed karst; caverns, caves, and corridors eaten away by the highly acid tropical environment (see Budel 1982) have opened the limestone directly down to sea level. Because rainwater sinks immediately into the karst, there is no significant surface water; water drops rapidly to a deep water table and is only marginally accessible through sink holes, springs, and human-dug wells. To the south, however, in contrast to the northern karst, the water of the mountains remains on the surface because of high river floodplain gradients, and the metamorphic bedrock is more resistant to the acidic tropical environments and karstification. As a result, tropical precipitation runs off rapidly soon after it falls (Aliphat Fernandez 1994:54). Changes in the water level of the Usumacinta River after rains can be as great as twenty-five meters in a single day. The seasonality of precipitation compounds the precipitous nature of this hydrological regime; it imposes a pattern of either too much or too little water. Needless to say, navigating such rivers is difficult.

The riverine district between the northern and southern regimes is remarkably different from either karst or mountains (Gates 1992; Pope and Dahlin 1989; Siemens 1978). That it contains lakes immediately reveals its difference from the dry surfaces of the north and the hydrologically volatile south. Because karstable limestones are underlain by metamorphosed and uplifted bedrock, water does not automatically fall from reach. Rather, karstic subterranean caverns provide large storage vessels for water at or near the surface. As a result, extensive, vegetation-choked swamps and lakes retain and maintain water at the surface year-round. This condition provides for slow-flowing rivers whose discharge is more evenly distributed across the months (Pope and Dahlin 1989; Schele and Freidel 1990:61; Siemens 1978). Unlike the northern karst, where there are no rivers, or the south, where rivers rage, scouring fluvial sediments, the streams of the riverine district develop rich floodplains, levees, and backswamps, more like rivers in the temperate zone.

As with the geology, the climate of the peninsula grades from north to south (Folan, Josserand, and Hopkins 1983). The north-south location of the climate ecotone is a response to global average temperatures (Gunn, Folan, and Robichaux 1994, 1995). Because of the importance of the overlay between the geological and climatic ecotones, the movement of the climatic ecotone creates three distinctive climatic regimes. First, as the globe warms, the tropics expand outward into former subtropical areas. When global temperatures are moderate, the ideal hydrological reservoirs of the riverine district reside

below the climatic tropical-subtropical ecotone dividing the year between wet and dry season (fig. 9.4b). This coincidence provided a cradle for the lowland Maya civilization beginning around 600 B.C. (Gunn, Folan, and Robichaux 1994, 1995). This cradle, however, was not without its problems. As global temperatures increased or decreased from moderate values, the climatic ecotone moved away from the riverine district (fig. 9.4a and c). During these episodes, the environment was either too dry (cold world), in the sense that the dry season was too long (fig. 9.4a), or too wet (hot world), in the sense that there was no dry season (fig. 9.4c); the tropics dominated the year-round. We will discuss the importance of a mixed wet and dry season later.

Naturally people and other biota have to adjust to these variable conditions. Adjustments are complicated by the fact that one or the other of the three regimes probably never appears every year; even under hot world

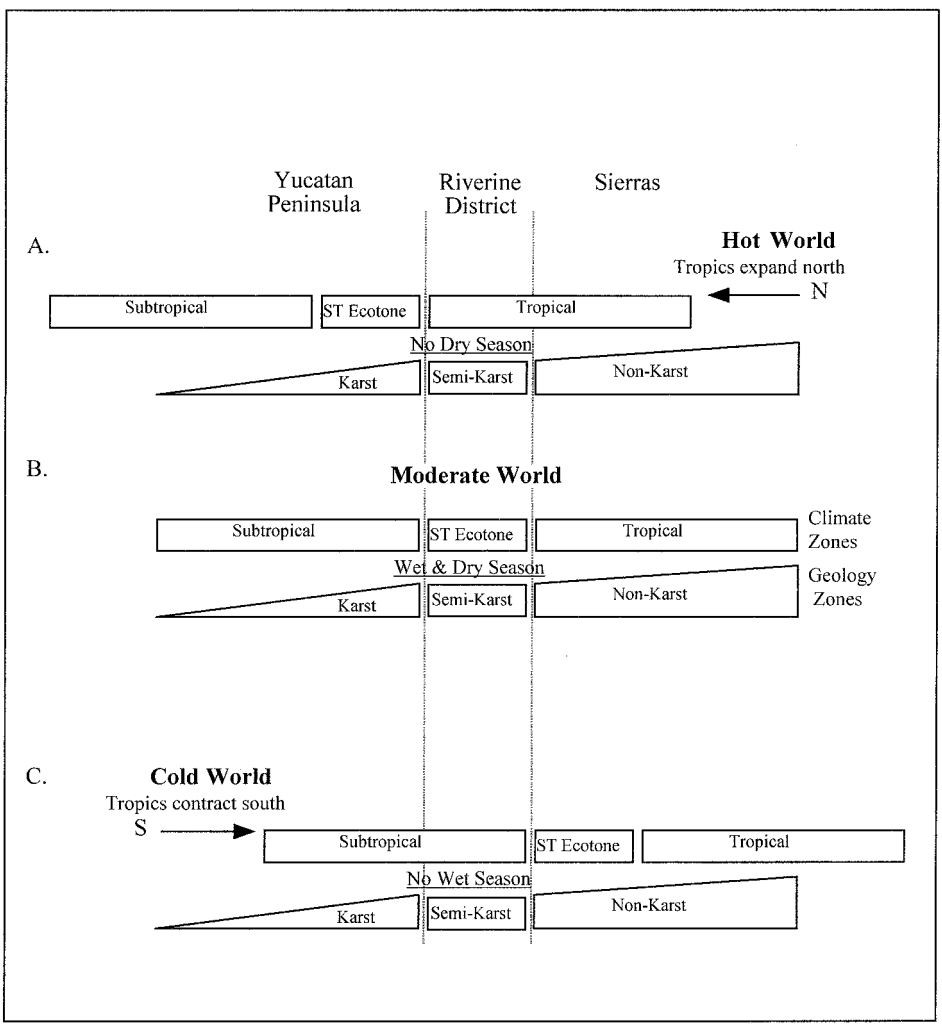

Figure 9.4. Processes of climatic and geological interaction in the southern Maya lowlands.

conditions there will be occasional cold, dry years (Gunn 1991, 1997; Gunn and Grzymala-Busse 1994; Gunn, Folan, and Robichaux 1994, 1995). This is the downside of the variability from a cultural perspective, and it necessitates risk management measures (Faust 1998:141). To manage risk, the people of every cultural period must have maintained a broad cultural memory repertoire addressing all three regimes; their period adjustments compensated for changing proportions of climate years in a period. It could be that the writing and complicated rituals of the Maya formed part of the cultural memory mechanism.

In our research into local agricultural practices, we found that upland slash-and-burn horticulturists of the region prefer an ideal mix of wet and dry season: a dry April to ensure a good burn of the slash and a wet May-June to initiate growth of the complex tropical gardens, or milpas (Folan and Gallegos 1992; Faust 1998; for a related modeling effort in Burgundy, see Crumley in this volume). When the seasonal environment became too wet or too dry for extended periods of years, Maya civilization would have been forced to emphasize labor-intensive riverine horticulture. It would seem that this demanding agriculture did not by itself provide sufficient subsistence surplus for the luxury of a burgeoning civilization, only maintenance of it. Following the Late Classic, the climate was viciously dry for over a hundred years toward the end of the Terminal Classic and then abundantly wet; in both periods, civilization hovered near the rivers and lakes. Maya civilization throve, however, when surpluses flowed from the vast, climatically enriched uplands. There could also have been a problem with increased frequencies of tropical storms during globally warmer episodes (Konrad 1984; see Gray et al. 1993 for the relationship of Atlantic hurricanes to global conditions). The sum of this geological-climatic conspiracy was a powerful climatic backdrop for the episodic pattern of lowland Mayan urbanism (Gunn, Folan, and Robichaux 1993). It appears that Mayan civilization often throve or faltered, other things being equal, on the coincidence of the geologic and climatic ecotones.

Extending our study of water supply responses to global conditions in additional river systems addresses a major current concern in climatology: the scrutiny of regional variation (Dunbar, this volume). Table 9.1 presents statistical analyses of global-regional relationships between annual average Northern Hemisphere tropospheric temperatures (NHTT) (Angell 1991) and discharge of three rivers of the Maya lowlands.[4]

Space Mosaic: Hydrological Response Surface for the Southwestern Maya Lowlands

If Candelaria River discharge is strongly responsive to changes in average NHTT, the significance of this for the human communities of the Candelaria watershed is that changes in global temperatures adjust the duration of the dry season and the onset of the rainy season from year to year (Gunn, Folan,

Table 9.1
Subregional Response Surface to Global Change, Indirect (ANOVA) and Direct (Multiple Regression) Effects

	Indirect (anova)		*Direct (Multiple Regression)*							
			Regression Betas					*Statistics*		
	C3 R^2	*C3 p*	*Solar*	*ApTr*	*WSOI*	*CO_2R*	*CO_2T*	*AdjR^2*	*F*	*p*
Champotón (1958–1986)*	0.18	0.107	–0.08	0.0	–0.17	–0.11	**0.57**	0.30	3.10	**.033**
Candelaria (1958–1990)	0.45	**< .001**	**0.60**	–0.29	0.08	0.27	0.34	0.55	8.42	**< .001**
Usumacinta Discharge (1958–1982)	0.10	0.950	**0.54**	0.12	0.02	–0.18	0.23	0.15	1.83	0.158
Usumacinta Precipitation (1970–1989)	0.08	0.517	0.47	–0.04	–0.13	**–0.60**	**0.47**	0.07	1.26	0.338

*Statistics with three outlier years—1977, 1978, and 1984—not considered.

C3 R^2 = R^2 of ANOVA.

C3 p = probability of the ANOVA finding not being attributable to chance.

Solar = Annual average international sunspot number to estimated rate of solar emissions.

ApTr = Apparent transmission of the atmosphere, i.e., amount of debris in upper atmosphere.

WSOI = Winter Southern Oscillation Index to estimate the state of El Niño.

CO_2R = Regression slope of carbon dioxide increase in the atmosphere.

CO_2T = Trend in the increase of carbon dioxide in the atmosphere.

AdjR^2 = Adjusted R^2

F = F-value for the multiple regression equation.

p = probability of the R^2 being attributable to random circumstances.

and Robichaux 1994, 1995). Prosperity pivots on effective accommodations of changes in seasonality forced by virtually cosmic interventions. Can similar or different phenomena be observed in the Usumacinta and Champotón rivers (see fig. 9.1)?

To address this question, we once again turned to global-regional functions based on NHTT and river discharge. The study period is between 1958 and 1994.[5] The Champotón River watershed is a relatively small drainage of about 259 km^2 (around 100 square miles). This compares to the 13,000 km^2 (approximately 5,019 square miles) of the Candelaria. The Usumacinta River possesses a huge watershed of 121,930 km^2 (approximately 47,077 square miles) spread across lowlands and mountains (Aliphat Fernandez 1994:48).

As we have shown before with shorter time series, the statistically measured relationship of Candelaria River discharge to NHTT is very strong (table 9.1).[6] The probability of this relationship resulting from the convergence of random events is far less than one in a thousand ($p < .001$). The Usumacinta and Champotón rivers, however, exhibit weak relationships to NHTT. In the case of Usumacinta River discharge, this was not unexpected, because of its great size and multifaceted topography. It spans a number of physiographic provinces (mountains, lowlands) and faces both the Pacific and Atlantic oceans.[7] Heterogeneous landscapes of great size expectably generate com-

plex relationships to global climate that elude simple statistics.[8] The weak relationship is not a liability, however, because we are concerned with both sensitive and insensitive hydrological subregions. The reason for this will emerge when we compare watershed sensitivities with the mosaic of subregional cultural chronologies.

Champotón River discharge is related to the tropospheric temperatures at an intermediate probability of $p = .107$ (or 107 chances in 1,000). $P = .107$ is generally regarded as a weak relationship, the usual statistical threshold being below $p = .050$ (or 50 chances in 1,000). Because the relationships involve complex landscape parameters, it would require an evaluation of the Champotón watershed—including geological, anthropogenic, and climatic factors—of a scope similar to that already done for the Candelaria River. This will be required to understand the relatively weaker relationship to tropospheric temperature. We would like to do this in a future study. In the meantime, the reasons for the weaker relationship can be inferred in a preliminary manner from the various global climate parameters analyzed by the multiple regression analysis in table 9.1. The regression analysis, which measures the relative strength of various atmospheric influences on discharge, implicates carbon dioxide trend ($CO_2T = 0.57$) as being related to Champotón River discharge rates.

This carbon dioxide relationship implies a possible reason for the weak impact of global climate change on Champotón River discharge. The carbon dioxide trend is the straight-line increase in carbon dioxide from 1958 to 1994. We suggest that Champotón River discharge is more heavily influenced by anthropogenic modifications of the basin—specifically, deforestation between 1974 and 1978 (Faust 1998:115; Gates 1993:152, 154, 163–165; Sandoval Palacios 1982)—than by direct global-scale intervention. Of course there are global-scale economic factors that connect local deforestation with increases in atmospheric carbon dioxide, but we do not need to be concerned with establishing this complex causal link now. We do need, however, to understand the link between local deforestation and local cultural habits, as this phenomenon occurred both in modern and Classical times (see Faust 1998:81–90 for review). A graphical examination of the relationship between discharge and CO_2T (fig. 9.5) shows a distinct bifurcation of discharge patterns after 1977. Before 1977 discharge simply increased with atmospheric carbon dioxide. After 1977, however, discharge relationships became much more complex. Some years, such as 1979–1981, continue to show a trend of gradual increase of discharge with increasing CO_2T (see P1 in fig. 9.5). Other years (1977, 1978, 1984) incurred substantial increases in discharge volume (see P2 in fig. 9.5). Both now and in the Classic period, such increases of discharge caused by anthropogenic deforestation of the landscape would have disturbed floodplain occupation along the lower Champotón River. When we examine the cultural mosaic of lowland city states, we will see that this phenomenon could have played a role in the total inter- and intrariverine settlement pattern.

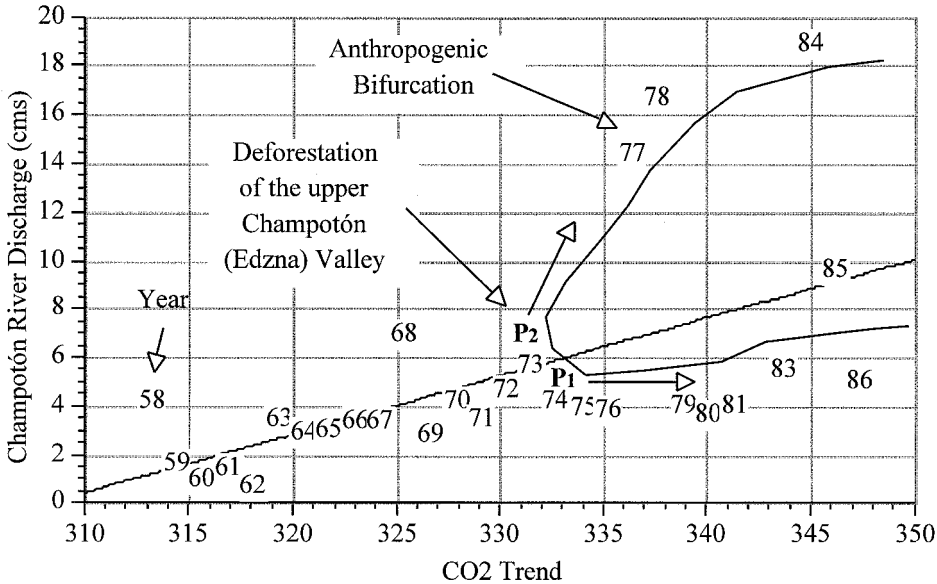

Figure 9.5. CO_2 trend and Champotón River discharge during the dry season.

The Champotón River is also farther from the Sierra del Norte de Chiapas and thus less in the rain shadow that shields the Candelaria River from the tropical Pacific El Niño. This could account for the hint of direct effect from El Niño in the regression betas (–0.17 in table 9.1).

To summarize then, the Candelaria River watershed, probably because of its peculiar geology—a semikarst riverine district shielded from the powerful influences of the Pacific El Niño—and relationship to the tropical-subtropical ecotone, has a strong regional relationship to tropospheric temperatures. The Champotón, located to the north of the riverine district, has greater relationships to human modification of the basin. The Usumacinta River discharge appears to have little relationship to the earth system climate variables; its immense size and multifaceted topography buffer it from global-scale atmospheric variations. How do these moisture change processes relate to the cultural time-space mosaic of the Maya lowlands?

Cultural Mosaic: Subregional Chronologies for the Southwestern Maya Lowlands

Extensive research in Maya lowland archaeology (Rands 1967; Adams and Jones 1981; Forsyth 1983; Marcus 1992; Folan 1992; Folan, Garcia Ortega, and Sanchez Gonzalez 1992; Pincemin Deliberos 1993; Proskouriakoff 1993; Demarest and Houston 1990; Dominguez and Carrasco 1994; Vargas Pacheco 1994; Millet Camara 1993), as well as emerging epigraphically based histories (reviewed by Freidel, this volume; Bricker 1995), have opened a floodgate of archaeological and historical information on the cultural chron-

ology of the Maya lowlands. Before the 1980s Maya civilization was a prehistoric culture known mostly through archaeological research. Thanks to advances in reading and understanding classical Maya inscriptions, however, the Maya have suddenly emerged as historic figures with names and personal problems. The combined impact of written and archaeological records is as stunning as the sudden comprehension of the earth system concept following space exploration or the verification of plate tectonics in the 1960s.

From this literature we have gathered information on important surges and recessions in cultural activity, in the opinion of local archaeologists, during the three-thousand-year history and prehistory of the southwestern Maya lowlands. These levels of activity are categorized as low/decline, active, or heavy and posted on a table of subregional syntheses (fig. 9.6). A period-by-period narrative of these classifications follows, as well as cross-references with global change episodes as they are currently understood (see, for example, Baillie 1994; Denton and Karlen 1973; Gunn 1994c, n.d.a). Previous uses of this methodology can be seen in Gunn and Adams (1981) and Messenger (1990).[9]

The cultural chronology of the southwest Maya lowlands is divided into eight periods (see fig. 9.6). Periods range in duration from two hundred to one thousand years; our primary interests lie in the first millennium A.D., during which most periods are about two hundred years in duration. This time resolution generally conforms to episodes of florescence and decline in the various watersheds and cultural subregions.[10]

In broad and general terms, the Maya lowlands exhibit great surges of construction in the Late Pre-Classic (400 B.C.–A.D. 250) and in the Late Classic (A.D. 600–800). These architectural enterprises were paralleled by other cultural developments, obviously involving the organization of large labor forces but also including the networking of millions of people and the development of an elaborate writing system. The general global temperature conditions across this period can be inferred from global sea level (fig. 9.7), which increases with global warming and decreases with cooling (Tanner 1993, n.d.). If watersheds measure the status of regions, ocean catchments measure the status of the world. Our concern here is the subregional variations within the broader Maya lowlands patterns and whether those local patterns are influenced by subtle subregional (i.e., watershed) responses to global climate change.

Proto Olmec-Maya/Early Pre-Classic (2000–1000 B.C.), Olmec-Maya/Middle Pre-Classic (1000–400 B.C.), Late Pre-Classic (400 B.C.–A.D. 250)

The early occupation of the lower and middle Usumacinta River valley (see fig. 9.6) began from mixing Olmec and Maya cultures during the Proto Olmec or Early Pre-Classic. The majority of the early Maya resided beside streams and along the edges of lagoons in simple villages, without marked indications of social stratification. Their major subsistence activity was fishing,

Period	Early Pre-Classic	Middle Pre-Classic	Late Pre-Classic	Proto-Classic, E. Classic	Late Classic	Terminal Classic	Early Post-Classic	Late Post-Classic
Date (-=BC +=AD)	-2000 -1000	-1000 -400	-400 +250	+250 +600	+600 +800	+800 +1000	+1000 +1200	+1200 +1550
Duration in years	1,000	600	650	350	200	200	200	350
South								
Petén: Tikal*								
Sierras: Palenque**								
Usumacinta middle = Chiapas		*Olmec*	*Petén*			River Oriented		
Coastal								
Usumacinta lower, Coast: Tabasco +		*Olmec*	*Petén*			*Chontal* No Inscrip.		
Candelaria lower, Coast: Itzamcanac					No Inscrip.			
Champotón Coast								
North								
Candelaria upper: Calakmul Basin								
Champotón upper: Edzna Basin								

*Dos Pilas, Aguateca, Altar de los Sacrificios, and Seibal in the Petexbatun
** Sierra del Norte de Chiapas
+ San Pablo and San Pedro River, Palizada River, Xicalanco Peninsula, Comalcalco, El Pájaro, Allende, El Encanto, Oaxaca, & Jonuta

Key:

Low/Decline--No evidence or little evidence of construction or aggregated populations
Active--Substantial evidence of construction and population aggregation
Heavy--Very substantial evidence of construction and/or population aggregation
No Information

Interior Labels
Olmec Influences from other subregions
No Inscrip. Other observations on influences

Figure 9.6. Chronology of southwestern Maya lowland subregional cultural activity.

including the gathering of aquatic resources such as crocodile, turtle, and shellfish. There were secondary emphases on hunting and horticulture.

Cultural activity, expressed largely in massive architectural construction projects, increased considerably on the lower Usumacinta during the Middle Pre-Classic (see fig. 9.6), which was contemporary with the Olmec civilization, but diminished during the Late Pre-Classic (Vargas Pacheco 1994).[11] Large habitation areas were located in lowland or floodplain sites in the middle Usumacinta of Tabasco (see Casasola 1979; Ochoa 1983); this shifted in the Late Classic, when the focus changed to more elevated cities such as Palenque (see below). Global climate was cooler during the Middle Pre-Classic, a condition tentatively recognized as the Homeric Minimum and reflected in the Tanner sea-level curve (see fig. 9.7).

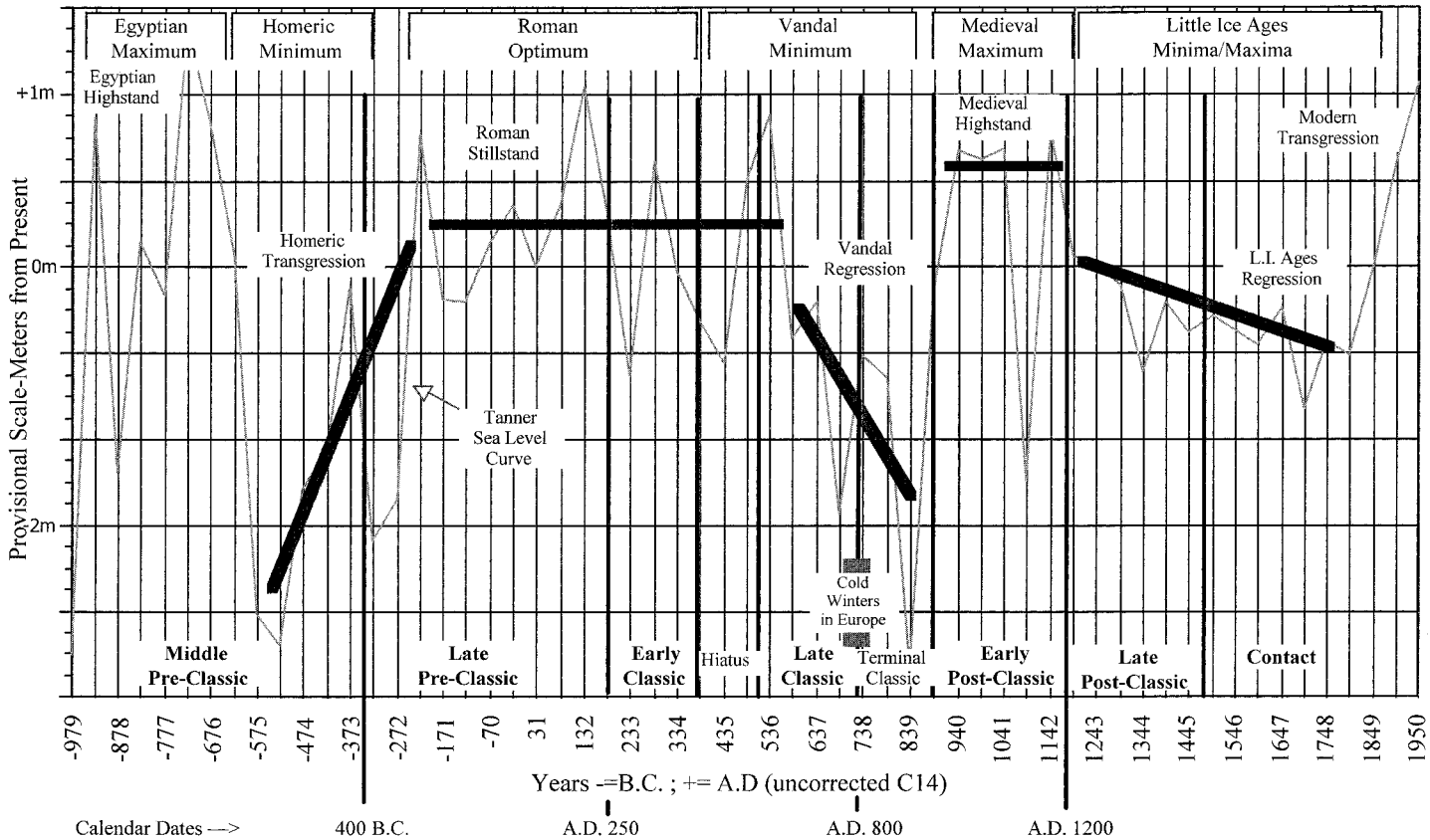

Figure 9.7. Global temperatures for the previous 3,000 years estimated by global sea level.
From Tanner 1993.

During the Late Pre-Classic (see fig. 9.6), the human presence in the lower Usumacinta River valley diminished. Conversely, activity expanded in the upper (Dominguez Carrasco 1994) and lower (Pincemin Deliberos 1993) Candelaria River valley, as well as within the upper Champotón River basin at Edzna (Forsyth 1983). If we follow the argument of our global-subregional response surface, these shifts in cultural activity suggest that during the Late Pre-Classic the change from globally cooler to warmer conditions favored more complex and sustained social organization in the Candelaria and Champotón drainages than in the Usumacinta watershed.

The complex interplay between subregions and global climate is intriguing. The Late Pre-Classic coincides with the global-scale Roman Optimum (300 B.C.–A.D. 200) episode, which is thought to have been a period of moderate global temperatures (Crumley 1993; Denton and Karlen 1973; Gunn 1994c; Gunn and Crumley 1991; Lamb 1977). Sea-level changes suggest a rather wide envelope of variation compared to, for example, the Little Ice Ages (see fig. 9.7). All of this indicates that environmental conditions in the riverine district were ideal for expanded cultural activity, with the tropical-subtropical ecotone hovering over the geological semikarst and a favorable mix of dry and wet seasons (see fig. 9.4b and related text). This climate-geology overlay supported sustained cultural activity in the Candelaria and Champotón drainages. Why it would have disadvantaged inhabitants of the Usumacinta watershed is less clear but of great interest. Perhaps in the Middle Pre-Classic, when residents of the Usumacinta were most active, the colder global conditions (see fig. 9.7) reduced the discharge volume and variability of the river, rendering it more habitable by facilitating water transportation. Widespread evidence of Olmec culture implies an economy based on trade relations, to which a stable river would have been a boon.

Early Classic (A.D. 250–600)

The Early Classic occupations of the lower Usumacinta River valley were not very important (see fig. 9.6). Vargas Pacheco (1994) argues that this was due to a decline of population or a movement of groups to other subregions. Similar demographic changes occurred in other subregions. In the case of the Candelaria River subregion, as well as in the Champotón River watershed at Edzna, the number of archaeological sites, few ceramics, and less architecture indicate that cultural activity declined during the Early Classic.

The Early Classic corresponds to the Vandal Minimum, a globally cooler and very unstable period. It was initiated around A.D. 200 by the most powerful episode of volcanism in the Holocene (Bryson and Goodman 1980). In the southwestern Maya lowlands, power shifted suddenly from El Mirador to Calakmul at this time (Folan 1992). The hydrological regimes of the two cities and their interaction with climate could have been a factor (Gunn, Folan, and Robichaux 1995). Another great shock of atmospheric disturbance and global cold followed in A.D. 536 (Baillie 1994; Gunn n.d.b). This

was contemporary with the Early-Late Maya Hiatus (Robichaux n.d.), during which the balance of power tipped from Tikal to Caracol in the Petén (Chase and Chase n.d.; Robichaux n.d.). The parameters of the Tikal-Caracol shift are textually documented (Chase and Chase n.d.), but we await clarification of this event in the southwestern lowlands.

The reason for low cultural activity in the Early Classic is unclear, but climate instability is implicated. Drought conditions are reported in some empirical studies and modeled by Gunn, Folan, and Robichaux (1994, 1995), although they do not appear in the lake cores from the northeastern Yucatan Peninsula (Hodell, Curtis, and Brenner 1995).

Late Classic (A.D. 600–800)

The period of maximum development in the Usumacinta River subregion after the Olmec appeared during the Late Classic (see fig. 9.6). In the Sierra del Norte de Chiapas, as well as along the banks of the San Pedro Martir River and the coastal subregion, local cultures and their habitation sites reached their maximum number and elaboration according to Vargas Pacheco (1994). Elements of this elaboration included architecture, stelae, inscriptions, and sculptures. Parallel developments progressed in the upper and lower Candelaria River watershed, according to Pincemin Deliberos (1993), but without stelae and other types of inscriptions. According to ceramic studies (Forsyth 1983), this trend does not seem to be detectable in the Champotón River watershed at Edzna. Forsyth notes, however, that several stelae, as well as architectural evidence, seem to support more development during the Late Classic than is evident in the ceramic record. Luis Millet Camara (pers. comm., October 1995) supports Forsyth's observations regarding architecture in Edzna in that he considers the period between A.D. 550 and 750 as one of strong sociocultural development. At Edzna, as elsewhere, the period between A.D. 750 and A.D. 950 is very significant, with the beginnings of Puuc-type architecture in the early years of the period. It is possible that the conceptual origin of Puuc was at Edzna, after which it spread rapidly into areas to the north (P. Becquelin, pers. comm. 1995).

Reasons for decline are clearly detectable in inscriptions. Mathews (1995) has quantified textual references to armed conflict in the upper and middle Usumacinta River subregion. He discovered that warfare increased substantially between A.D. 633 and A.D. 810. By far the greatest number of conflicts per twenty-year *katun*, a Mayan measure of time, were registered in the katun between A.D. 790 and 810. Subsequently there was a marked decrease in the dedications of stelae.

Seasons of warfare are also detectable in inscriptions. For the upper and middle Usumacinta River subregions, Mathews (1995) determined that most conflicts took place during the months of November, December, January, and February. This could represent the period between harvest and preparation of fields for planting. Warfare in this season would have been feasible in

some parts of the Maya region where there is only one harvest a year, or at most two.

Marcus (1992:431, table 11.1) identifies the times of many battles in the southern Maya lowlands in a slightly broader annual time frame. According to her, the preferred season of warfare began in November, probably after harvest, and continued until May. May is not only the end of the dry season but is included in the time of burning and planting in slash-and-burn horticulture. Planting takes place after the first two or three heavy rains around May or June. Thus the season of warfare slightly overlaps the agricultural calendar as it is currently understood. In the present-day Chol-speaking areas of the lowlands near Palenque where true resident populations still persist, rain days are anticipated on 3, 5, or 10 May, and planting occurs two weeks before (K. Josserand, pers. comm. 1995). As warfare was probably limited to the dry season because of logistical considerations, careful study of war records could reveal information on the length of dry seasons at various times. Dumond (1998) reports that during the War of the Castes in the 1800s, Maya military movements depended on milpas; if this was the case in the classical period, it could be that widespread warfare was not possible without healthy upland milpas.

Demarest (in Sharer 1994) reports that in the upper Usumacinta River drainage maximum development occurred during the beginning of the Late Classic and continued to A.D. 761. At that time, Ruler 4 of Dos Pilas was captured and sacrificed at Tamarindito. Aguateca became the principal political capital of the Petexbatun, a part of the riverine district. That arrangement politically unraveled about A.D. 800 when the Petexbatun was apparently divided into what Proskouriakoff (1993) calls "principalities." The principalities increasingly warred with each other.

Perhaps groups from the Gulf Coast dominated the Petexbatun during the subsequent Terminal Classic. This seems to be the case in surrounding areas as well. It was during the Classic Period, as well as the following Terminal Classic, that the maximum density of population was reached in the lower Usumacinta River valley. During and around A.D. 800–1000, however, development diminished in the lower Usumacinta River valley below Tenosique, in Tabasco, and elsewhere. Waning cultural energy was manifest in reduced new temple and palace construction, as well as fewer inscriptions at major sites such as Palenque, Yaxchilan, Tikal, and Calakmul (Dominguez Carrasco 1994). Other cities began to decline in importance and were eventually abandoned.

The ascendance and decline of the Late Classic could be related in some complex fashion to global climate. A number of factors were obviously involved (see Freidel, this volume). The most active period, however, falls in the 700s, with decline evident in various regions before or by A.D. 800. There are many indications that the 700s were a time of equitable global climate. Stable and moderate global climate would have kept the ecotone over the riverine district, providing the agricultural surpluses necessary for cultural elabo-

ration. Similar and contemporary sustained developments occurred in Europe with the establishment of a Carolingian North Sea trading sphere, which collapsed suddenly in A.D. 829, the year the Nile River froze (Lamb 1977:427).

The period was concluded by an extremely cold Northern Hemisphere between A.D. 760 and 840 (Gunn 1994c, n.d.a; Lamb 1977:427); this of course is the time of the epic collapse of Maya civilization. During the globally cold years between A.D. 760 and 840 (see fig. 9.7), as is anticipated by our model of the tropical-subtropical ecotone slipping south with cooling (see also Folan, Josserand, and Hopkins 1983 and Gill 1994 for global climate mechanisms), the Maya lowlands became exceedingly drought prone (Hodell, Curtis, and Brenner 1995; Curtis, Hodell, and Brenner 1996), and Maya civilization retreated to more hydrologically reliable riverine and lacustrine locales.

Terminal Classic (A.D. 800–1100)

Although Ochoa and Vargas Pacheco (1979) once thought that natural causes could have brought about a general decline in construction and population aggregation at the end of the Late Classic, they later reasoned that this was not the case, instead emphasizing a combination of causes. The mosaic of collapse is more varied than previously thought, leading to the definition of the Terminal Classic period (see fig. 9.6). The causes of collapse in the Petén and Sierras include a marked difference in social classes, population movements, and warfare problems indicated by the frequent appearance of military-associated images on stelae and murals. There was an intensification of public works, perhaps resulting in antagonisms between the haves and the have-nots (Vargas Pacheco 1994). The archaeological record at Altar de Sacrificios and Seibal indicates the introduction of powerful new groups of people, perhaps Chontales. These would have contributed to the lack of control and imbalance in cities up and down the Pasion and Usumacinta rivers.

The abandonment of Palenque during the A.D. 800s (A.D. 850, according to Vargas Pacheco, pers. comm. 1995) and of other elevated sites was followed by the formation of smaller sites surrounding Palenque on an intermediate elevation plain (Vargas Pacheco 1994:12). At this time, then, the settlement pattern returned to something like its ancestral lowland form (see the discussion of the Late Pre-Classic period, above). Toward the end of the Late Classic period, populations moved toward the rivers, dominating the floodplains and the coast. They asserted their maximum influence during the Terminal Classic, when the region took on a grand importance along the lower and middle Usumacinta River. Included in this sphere of influence were the San Pedro, San Pablo, and Palizada rivers, as well as the coast. At the coast, a great number of cities of varying importance were built around the time of the collapse of Palenque: Comalcalco, El Pàjaro, Allende, El Encanto, Oaxaca, Jonuta, and others. Handmade bricks were utilized in their construction, but without Classic Maya stelae and/or other types of inscriptions. Following an apparent lull of a hundred years (A.D. 800–900), the Chontales reached their period of

maximum construction activity and population aggregation between A.D. 900 and the beginning of the Post-Classic, in A.D. 1100.

Apart from the coastward movement of populations, which was probably influenced by the ascent of sea-borne trade (Adams 1977), the Terminal Classic is striking for its similarity to the Late Pre-Classic in the Usumacinta Valley. In both cases, the suggestion posed by cross-checking with the global-local climate model is that colder global conditions make the floodplain of the Usumacinta River more habitable, and the model implies that this is because of reduced volume and variability in river discharge and flooding.

Post-Classic (A.D. 1100–1550)

The Post-Classic (see fig. 9.6) period is characterized by a marked decrease in archaeological remains. The focus of activity was the lower Usumacinta River valley, probably in the San Pablo and San Pedro River valley, and along the Campeche and Tabasco coasts, including the Champotón River valley. The Champotón River subregion apparently reached its peak activity during the Post-Classic (Vargas Pacheco 1994). There was little presence in the middle Usumacinta River valley. Although the occupation of the lower Usumacinta and San Pablo and San Pedro rivers was minimal during the Early Post-Classic, there was more activity evident along the Candelaria River and on the Peninsula of Xicalanco. Ethnohistoric sources indicate a considerable population of this region at the time of contact, but the archaeological record does not. On the Candelaria River, Itzamcanac was built from the Pre-Classic through the Post-Classic. It emerges as an important urban center ethnohistorically and archaeologically (Vargas Pacheco, pers. comm. 1997). Edzna, according to Forsyth (1983), had been almost completely abandoned.

The global climate was highly varied during this period. It ranged from warmer than the present during the Medieval Maximum (A.D. 900–1250; see Eddy 1994) to a very cold early episode of the Little Ice Ages (A.D. 1250–1450) in the 1300s. It is possible that the globally cold middle 1300s were caused by an eruption of the El Chichonal volcano in the nearby Mexican highlands ten times greater in magnitude than the 1982 eruption (Gill 1994; Rampino and Self 1984). Lamb (1977) reports that in Europe the coldest winter of the second millennium was probably in the 1340s. As discussed earlier, this signals a cold Northern Hemisphere with the tropics shifted south and consequent drought in the Maya lowlands. The period ended with the moderately warm Renaissance Optimum (A.D. 1450–1570). Such marked instability under cold world conditions would have translated into variable local conditions; without a stable environmental platform on which to consolidate cultural continuity, lowland cultures would contract toward watery environments—rivers, lakes, and oceans—and relied on trade relations to buffer environmental instability. The ocean-going traders observed by Spaniards and the intensive riverine agriculturists found in the lower Candelaria River system by Cortez in the sixteenth century (Gunn, Folan, and Robichaux 1995; Siemens and Puleston 1972) conform to this perspective.

Discussion

It is clear from this subregional synthesis that cultural activity was shifting in focus and asynchronous across lowland subregions (fig. 9.8). Only the Early Classic period displays a uniform pattern of construction, ceramic utilization, and/or stela creation activity. All others contain all three activity modes. During the Late Pre-Classic, the Petén, lower Candelaria, and upper Candelaria/Champotón subregions exhibited heavy cultural activity. The Late Classic was most uniformly active, with seven of eight subregions showing heavy construction and stela creation. The Terminal Classic was only a little less vigorous, with six of eight subregions in heavy activity. During the Early Post-Classic, however, all subregions were in decline except the Champotón Coast.

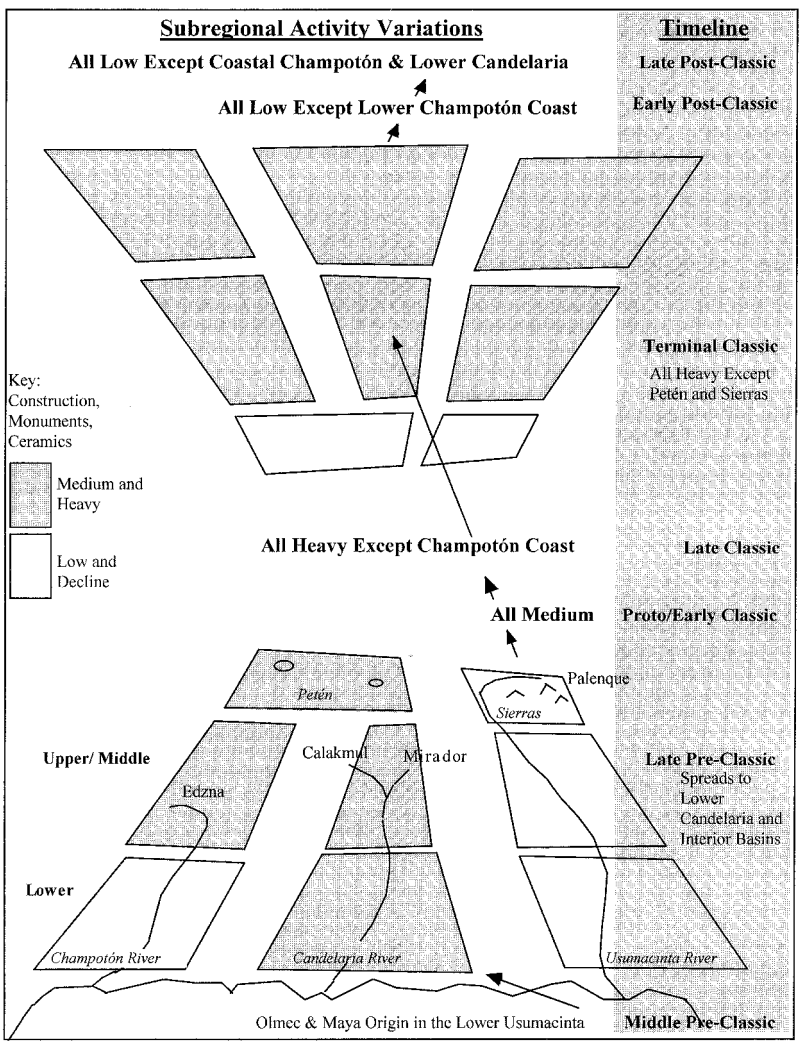

Figure 9.8. Abstracted subregional variation in cultural activity.

The shifting pattern of urbanization began in coastal Usumacinta during the Middle Pre-Classic. During subsequent periods, the dominant subregions changed decidedly.

- In the Late Pre-Classic, all reaches of the Usumacinta experienced only modest development, while the lower Candelaria and the interior basins (Champotón at Edzna, Candelaria at Calakmul, Petén at El Mirador, Tikal, etc.) grew rapidly.
- This burst of Late Pre-Classic activity was followed by a quiescent Early Classic. There was some abandonment of notable cities such as El Mirador (Hansen 1990).
- During the Late Classic, the runup to extravagant urbanism was rapid and general, except in coastal Champotón, where development remained modest. Toward the end, the Puuc architectural style was evident. That its popularity spread from the north suggests southward flow of influence.
- As the Late Classic regional states fragmented, the Terminal Classic opened with the central Petén and the Sierras disintegrating first; they were followed by the northerly interior basins including Calakmul and Edzna halfway through the period. Interestingly, though having lost evidence of writing, the lower Usumacinta, under the influence of the Chontal culture, burgeoned at this time. People built many coastal cities; the entire drainage appears to be under Chontal influence. On the lower Candelaria, there was construction at Itzamcanac and elsewhere.
- Through the general decline of the Early Post-Classic, the only thread of heavy cultural activity was in the lower Champotón along the coast. During the Late Post-Classic, coastal Champotón was joined by lower Candelaria, with modest cultural activity as inferred from archaeological and ethnohistorical evidence.

When evaluated relative to the climate and hydrology models, at least three interesting patterns emerge.

1. During the Early and Middle Pre-Classic, lowland civilization originated in the coastal Usumacinta subregion. In the Late Pre-Classic, there was only modest development in the entire Usumacinta, while construction flourished in the interior basins and the lower Candelaria. Our externally forced data model projects a shift from dry to moderately moist climate between the two periods. Hodell, Curtis, and Brenner's (1995:393) oxygen isotope cores imply similar conditions. It could be that during these times of greater moisture, the Usumacinta subregion was encompassed by the tropics, experienced a highly variable annual hydrological regime, and was thus generally less appealing than the more ecotonal interior basins. Increased moisture could also explain the choice of higher elevations for cities such as Palenque.

2. Following A.D. 850, more elevated cities in the Sierras, or upper Usumacinta River, were abandoned, while construction on the floodplain

and coastal Usumacinta expanded. Our externally forced model of the great drought places its onset before A.D. 750, and it persisted until after A.D. 950 (Gunn, Folan, and Robichaux 1994, 1995). Hodell, Curtis, and Brenner's (1995:393) sulfur/oxygen isotope determinations suggest an onset at about A.D. 800 with continuation until A.D. 1000. A comparison of the oxygen isotope and sulfur levels suggests that high evaporation began about A.D. 800, but extreme negative impacts on hydrology, as measured by sulfur, were delayed twenty-five to fifty years. This second date corresponds to the abandonment of Palenque and occupation of the Usumacinta floodplain.

3. In the comparative discussion of discharge regimes, we found that the Champotón was severely impacted by human activity. Deforestation in the modern situation appears to increase substantially the magnitude of floods, creating a bimodal distribution of discharge volumes. It is interesting that as long as the upper Champotón at Edzna was culturally active during the Late Classic, the lower Champotón remained quiescent (Andrews 1977; Ruz Lhuillier 1969; Vargas Pacheco 1994; Eaton and Ball 1978). After the decline of Edzna in the Terminal Classic, and presumably reforestation of the watershed and reduction of flood volume, coastal Champotón was the only subregion that was heavily active in the Post-Classic.

Conclusions

The Candelaria watershed is susceptible to astronomical and geophysical influences. Its vast swamps and hydrological basins serve as amplifying mechanisms for external variables. The extreme sensitivity of the Candelaria River discharge to global climate conditions is made all the more interesting because its neighboring rivers are largely insulated from global-scale influences. If the Candelaria River watershed and presumably other similar areas of the riverine district are as susceptible to global climate change, then the Maya could have had practical applications for their grand (earth system?) cosmology. Perhaps at the root of Maya civilization was some sort of management system that was sensitive to the subtle cyclical variations of moderate world climate (Puleston 1979; Folan and Hyde 1985). As suggested in the discussion of ecotones, neighbors in adjacent watersheds could have fallen under the cultural sway of the riverine district groups. Because of their cosmology the Maya possessed a superior ability to prognosticate patterns of cyclical environmental changes. These changes were most characteristic of the riverine district but expressed less precisely in subregions outside the ecotonal riverine district subregion.

The Champotón River watershed is currently under the sway of anthropogenic influence to the near-exclusion of astronomical and geophysical influences. This probably reflects the limited area and coastal plain location that make it a more fragile environment. This fragility is expressed by excessive discharge events in the post-1975 discharge record following deforestation.

This could explain why at some times there was much activity along the upper reaches of the Champotón watershed, as during the Late Pre-Classic and Late Classic at Edzna, or in its lower reaches during the Post-Classic, but never in both areas at the same time. The death and reforestation of the Edzna Valley rendered the lower Champotón watershed habitable. Will deforestation and the construction in the upper Champotón basin of *ejidos*—large communal farms dedicated to rice production—result in a similar situation that endangers the city of Champotón as global warming proceeds? The extreme bifurcation of discharge volumes after 1977 suggests that it will and that this should be investigated.

In spite of its apparent lack of statistical response to global temperatures, the Usumacinta River provides serendipitous insights. It appears that globally cold times tame the mighty Usumacinta. Our analysis of Usumacinta discharge suggests that it would be, at least in its floodplain aspect, a very stable water source because it is not sensitive to cyclical vicissitudes as the two northern rivers are. This is because it is situated well within the tropics and drains the slopes of towering mountains as well as broad wetlands. Its watershed faces toward the Pacific Ocean, with its moisture laden El Niño–derived airmass, and the Atlantic, with its tropical storms. That the middle Usumacinta Maya left lofty Palenque and built their Terminal Classic cities on the floodplain, as they had in the equally cold Pre-Classic, provides valuable insight into the duration and severity of the drought modeled by this project and documented by various paleoclimatological measurements. At the same time, it shows that, close to the river, water was reliable in the worst of times. The Usumacinta floodplain appears to be more habitable during colder global conditions because of less water and probably less variable discharge, which would facilitate river traffic.

The general concentration of Post-Classic architectural efforts along the coast, especially along the Champotón and Candelaria rivers, probably has significance beyond the development of coastal trade. Why were not the upper reaches of these rivers reoccupied following the great drought of the ninth and tenth centuries? (See Tainter [1988, and in this volume] for similar problems with the Romans.) Many factors undoubtedly contributed to this, including degraded soils, lost hydrological infrastructure, and perhaps even social factors such as cultural memories of the ill that befell those who built great cities in the interior. Changed climatic conditions should also be considered. Folan, Josserand, and Hopkins (1983) have shown that the ethnohistorical and historical periods witnessed a number of shifts in environment with social consequences. Was the variability of the climate of the Yucatan Peninsula following the Classic Maya tenure of such a character as to discourage vast investments in society and structure? Was the draw of populating and trading along the coast fed by abandonment of the interior and reforestation of the former cityscapes? Such questions can only be pursued through a thorough understanding of both the environment and the social dynamics of the historic and modern lowland Maya.

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Notes

1 A readily available source of a broad range of this information, both in a monthly near-real-time publication and on the Internet, is the *Climate Diagnostics Bulletin* published by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Centers for Climate Prediction (http://nic.fb4.noaa.gov). Also available for climate forecasting is the *Experimental Long-Lead Forecast Bulletin* by the same organization. The World Meteorological Organization also distributes monthly bulletins on global climate conditions.

2. In our study area, an example of long-term adjustments to climate variation is found in the relationship between the towns of Pich and Bolonchen Cauich in the Edzna Valley of the Champotón watershed. Before modern deep wells, families maintained marital relationships between elevated Pich and Bolonchen Cauich in the valley floor. When drought dried the reservoir and wells in Pich, families retired to the homes of their marital relatives in Bolonchen Cauich (Faust 1998:83). Marriages still tend to be between people of the two villages.

A mysterious case of plants with the unusual capacity to forecast the weather are the fabled pecans of the southern United States that seem never to be caught unaware by late frosts.

3. The troposphere is the component of the atmosphere, the lower atmosphere, that controls the locations of circulation patterns and moisture of atmospheric circulation and interacts directly with ocean and land surfaces and biocultures. The upper atmosphere, or stratosphere, which is above approximately thirty thousand feet, interacts more with the solar and geophysical subsystems and thus has its own suite of characteristic temperature changes apart from the lower atmosphere (Angell 1991). Of course the upper atmosphere is also anthropogenically influenced as the recent and ongoing depletion of upper atmospheric ozone testifies (Angell 1993). Variations in upper atmosphere temperatures are generated by changes in solar emissions and variations in the amount of sun-blocking debris, largely supplied by

volcanic eruptions. Because there is little moisture in the upper atmosphere, debris such as sulfur dioxide particles or aerosols can remain aloft for years.

4. The rivers are selected based on the availability of data between the years 1958 and 1994. So far as we know, these are all of the data for that period (appendix 9.1). The tables parallel those published in previous studies of the Candelaria River (Gunn, Folan, and Robichaux 1994, 1995). Methodological and parameterization issues are addressed in those articles. Relationships between NHTT and river discharge were determined by analysis of variance probabilities, a nonlinear regression-based statistic, and thus are very conservative.

5. Discharge was observed for the three rivers only intermittently, beginning in the 1980s. As a result, the data sets are not strictly comparable in time (appendix 9.1). Because we are concerned with the processes rather than the history of global-regional relationships, there is no particular reason why the data need to be from the same years, although it would be helpful. It is important that enough years are present for each river to represent a wide range of potential global-regional conditions. For purposes of statistical analysis, such relationships probably require about twenty or more years. Because the 1980s were globally the hottest years on record, diminished record keeping during that period is probably the greatest liability to this analysis as it diminishes representation of hot world conditions.

6. The first two columns in table 9.1 present analysis of variance statistics for relationships between January-to-August discharge from the three rivers and precipitation data from the Usumacinta River region at Boca del Cerro. Further details of these analyses are available in tables in appendix 9.2.

7. To focus on the area east of the mountains, for example, the Maya lowlands, precipitation data were analyzed from Boca del Cerro. The relationship between global temperatures and Boca del Cerro precipitation appears to be due to random circumstances ($p = < .517$). Does this indicate that even in this limited area north of the mountains the relationship between tropospheric temperature and regional moisture is weak, or is the reason the inherently unreliable nature of narrowly based station data? This will have to await further research.

8. This has frequently, though not universally, been our experience in analysis of rivers originating in mountains (see table 2 and related discussion in Gunn, Folan, and Robichaux 1995). The watershed does not meet the criterion of locally earned water that generally makes watersheds useful for the study of sensitivity to global conditions.

9. Obviously this falls a step short of a full evaluation of the interactive networks of environmental and social systems in the subregions. We anticipate, however, that as hypotheses (Gunn and Adams 1981) proceed toward evaluation in the Candelaria drainage (Gunn, Folan, and Robichaux 1994, 1995), so will more stringent standards of investigation be applied to the subregions of the Maya lowlands as the difficult task of forwarding explanatory concepts proceeds. The following discussion provides a first approximation of the logical interrelationship of conditions that will require further attention to substantiate.

10. Thanks to the reading of texts, events now can be deciphered at much finer timescales; ultimately we anticipate a twenty-year-interval analysis. This is the length of one katun and thus the interval at which monuments with inscriptions were typically erected.

11. Vargas Pacheco (1994) equates those two phases with the Pre-Mamon, Mamon, and Chicanel phases of the central southern Maya lowlands (Petén) Pre-Classic Maya, whose crossdating is clearly demonstrated by ceramic wares (Rands l967).

APPENDIX 1. RIVER DISCHARGE AND PRECIPITATION DATA

Key

Grow—Growing season average monthly precipitation.

C4, C3—A division of global average temperatures into 4 (or 3) categories, ranging from coldest (1) to warmest (4 or 3).

Candelaria River at Candelaria, Campeche, Mexico, Discharge in Cubic Meters per Second

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Grow*	*C4*	*C3*
1958	31.6	23.5	21.6	19.3	21.1	63.2	74.2	58.8	51.2	62	45.8	41.8	39.2	4	3
1959	43.2	32.1	26.1	23.8	25.1	*31	*25.4	29	31.1	37.9	52.6	40.2	29.5	4	3
1960	28.2	24.3	20.8	19.8	20.8	24.4	32.7	40.4	54.9	83.5	63.7	50.2	26.4	3	2
1961	37.1	30.4	26.8	23.7	21.1	21.3	28.2	41.9	38.1	39.3	59.5	36.5	28.8	4	3
1962	32	22.5	20	16.8	16.5	13.7	13.8	14.6	18.4	32.2	30.5	19.9	18.8	3	2
1963	17.1	16.5	15.7	14.5	14.1	12.2	*12.2	*12.1	106	309	221	108	14.3	2	2
1964	61.2	43.1	36	25.2	24	27.1	*34	*28.6	31.3	35.1	33	39	34.9	2	2
1965	20.6	19.1	18.7	18.3	16.5	16.7	18.4	22.2	27	55.4	69	40.5	18.8	1	1
1966	27	21.2	20.8	18.7	19.6	21.4	*26	*25	43.6	61.8	79.3	43.7	22.5	3	2
1967	33.8	35.5	27.7	24.9	22.2	*23.1	*21.8	*20.5	23.9	95	48.5	25.8	26.2	2	2
1968	22.4	18.5	18.3	17.5	15.8	*28.3	*20.1	49.5	67.3	100	145	70.9	23.8	1	1
1969	41.2	26.1	19.9	21.3	*21.9	*21.7	30.4	36.9	93.8	116	72.4	46.9	27.4	2	2
1970	33	27.2	22.9	19.9	19.2	21.9	22.9	46.7	70.9	86.3	73.4	29.2	26.7	3	2
1971	20	16.1	15.5	16.3	15.8	14.9	15.2	17.6	29.4	20	14.2	13.3	16.4	1	1
1972	12.5	12.6	10.1	10.5	10.4	23.9	33	43	60.8	66.9	54.8	47.9	19.5	1	1
1973	40.4	19.8	15	15.5	15.2	*15.2	*14.7	40.1	132	132	91.8	55.9	22	4	3
1974	30.5	20.8	16.8	15.7	15.4	15.9	16.8	36.3	50.7	93.5	48	18.4	21	1	1
1975	15.5	12.7	10.1	8.7	8.7	*11.1	*10.2	21.9	53	144	96.3	43.9	12.4	2	2
1976	21.3	13.5	15.4	16.5	17.1	24.3	*40.6	*34	79.3	62	39.3	45.4	22.8	1	1
1977	29.4	21.6	24.2	17.7	10.6	16.6	19.6	23.8	27.6	37.5	25	17.9	20.4	3	2
1978	15.5	12.5	12.5	10.4	12.7	19.9	*35.5	*29.7	71.1	121	107	76.3	18.6	2	2
1979	51.9	32.4	25.4	21.1	*20	*19.1	39.5	46.3	68.6	174	173	117	32	3	2
1980	73.7	45.1	34.5	27	24.3	31.9	40.8	45.3	94.2	175	141	107	40.3	4	3
1981	51.7	46	38.7	28.8	22.4	66.2	116	122	110	121	107	73.3	61.5	4	3
1983	70.3	50.6	37.7	33.7	30.3	27.8	33.1	34.9	55.9	93.6	113	82.9	39.8	4	3
1984	40.9	32	24.9	17	20.2	23	33	41	93.6	226	188	111	29	2	2
1986	36	25	21	21.8	27.8	34	34	42	59.7	46.6	50.1	36	30.2	3	2
1987	24	18.3	17.6	18	17.4	19.2	31.8	41.1	59.4	239	149	62.8	23.4	4	3
1988	53.2	51.4	47.1	37.4	21.6	29.9	49.3	56.2	106	194	173	120	43.3	4	3
1989	77	41	41.1	35	32.5	41.9	42.4	45.6	194	279	277	126	44.6	4	3
1990	76	40	35.8	25	14.3	34.3	38.6	55.4	90.2	65	57	51.3	39.9	4	3

* = interpolated values in place of missing data

Champotón River at Canasayab, Campeche, Discharge in Cubic Meters per Second

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Grow*	*C4*	*C3*
1958	2.56	*1.52	*0	*4.20	*3.62	6.05	7.39	7.65	*7.75	4.20	2.45	2.89	2.96	4	3
1959	2.22	1.85	*0	*1.61	1.72	1.61	1.64	1.87	1.90	2.30	1.69	1.45	1.36	4	3
1960	1.47	1.58	*0	*1.54	0.90	0.68	0.68	0.72	2.47	6.02	*1.94	0.94	0.75	3	3
1961	0.55	*0.8	*0	*1.05	0.72	0.74	1.23	6.34	19.88	21.95	8.13	0.75	1.20	**	**
1962	0.64	0.2	*0	0.58	0.97	0.78	1.23	1.17	8.11	7.42	1.14	0.90	0.70	3	2
1963	1.62	2.19	*0	1.29	2.81	2.66	2.56	14.58	133.17	147.01	6.13	3.16	2.37	2	2
1964	3.11	2.63	*2	*2	3.19	2.87	3.38	3.65	9.01	23.36	2.80	2.47	2.35	2	2
1965	2.03	2.12	*0	*2.41	2.31	2.44	4.93	7.47	4.17	26.47	11.12	2.48	2.66	1	1
1966	2.52	2.19	3.06	3.48	2.73	2.31	5.03	5.69	20.58	45.92	4.00	2.51	3.38	3	2
1967	1.82	*1.78	*2.56	2.45	2.68	2.81	3.51	8.76	26.04	16.95	10.09	3.49	2.75	2	2
1968	3.25	1.97	*0	*3.74	2.58	13.60	4.78	25.46	13.47	18.79	9.22	3.01	6.46	1	1
1969	2.83	1.81	2.31	3.21	2.87	2.53	3.00	3.68	21.75	102.31	10.64	3.52	2.78	2	2
1970	4.03	4.08	3.68	3.48	3.30	3.84	4.19	6.39	9.47	15.08	8.39	3.72	4.12	3	2
1971	3.88	3.86	3.26	2.81	2.72	2.82	3.66	4.32	14.59	20.43	3.71	3.84	3.42	1	1
1972	3.55	3.46	3.40	3.32	3.43	4.09	10.49	5.00	16.28	8.84	4.19	3.50	4.59	1	1
1973	4.18	4.00	3.92	4.52	3.62	4.13	4.07	16.32	50.35	29.83	5.61	3.67	5.59	3	2
1974	3.55	3.29	3.08	3.14	3.19	3.76	8.35	4.60	5.18	5.31	4.59	4.34	4.12	1	1
1975	2.59	2.61	2.81	2.63	1.75	21.75	4.53	12.65	5.56	172.18	9.64	2.79	3.92	2	2
1976	2.89	3.02	2.96	2.52	2.53	3.35	3.47	9.84	86.91	16.63	4.25	4.69	3.82	1	1
1977	4.10	3.20	3.52	3.35	3.00	4.73	11.38	81.69	24.04	60.39	6.65	4.36	14.37	3	2
1978	3.50	3.59	3.35	3.47	5.57	34.54	41.92	37.40	144.59	218.31	58.39	6.60	16.67	2	2
1979	4.62	4.41	4.06	4.11	1.64	2.56	5.79	4.71	109.11	175.83	7.73	3.42	3.99	3	2
1980	*3.33	*3.45	*3.47	3.20	*4.07	3.76	3.92	*3.54	98.97	*47.37	*51.65	4.85	1.36	3	2
1981	3.51	3.03	3.28	3.28	3.04	3.86	5.15	6.87	55.01	91.24	12.38	3.44	4.00	3	2
1983	4.56	4.8	4.48	4.57	4.31	4.76	5.62	10.58	29.92	10.27	5.26	4.68	5.46	4	3
1984	4.39	4.4	4.25	4.45	34.96	55.9	4.4	38.12	117.68	36.16	3.3	3.24	18.86	2	2
1985	4.44	4.03	4.46	4.21	8.95	7.17	3.17	40.2	18.1	19.95	5.84	*5.96	9.58	1	1
1986	6.08	4.22	3.99	4.14	4.24	5.31	4.49	7.32	25.73	19.65	4.43	4.5	4.97	3	2

* = interpolated values in place of missing data

Usumacinta River, Chiapas, Mexico, Discharge in Cubic Meters per Second

Stn	*Year*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Grow*	*C4*	*C3*
1 = Boca del Cerro																
1	1958	996	634	630	454	703	2740	3332	2641	2090	2318	1486	2255	1516	4	3
1	1959	1322	847	861	795	748	1722	1564	1898	1783	2338	2556	1427	1220	4	3
1	1960	940	700	571	454	641	1836	2530	2784	4470	4050	2539	1798	1307	3	2
1	1961	1604	1553	1112	858	595	1775	2664	2568	2224	2796	2733	1171	1591	3	2
1	1962	912	822	729	980	755	1236	2173	2195	2961	2934	2055	970	1225	3	2
1	1963	671	670	638	446	299	449	1698	1778	3281	3302	2261	1231	831	2	2
1	1964	922	655	535	450	393	1285	3190	1858	2278	2242	1270	2455	1161	2	2
1	1965	1655	1146	795	545	472	780	2468	2282	2745	4534	4183	2127	1268	1	1
1	1966	2031	1331	1191	1230	1007	2168	3671	2317	4040	4089	2576	1472	1868	3	2
1	1967	1289	1253	980	827	525	1206	2608	2591	1950	5012	3406	1747	1410	2	2
1	1968	1489	1261	843	649	646	2319	2544	3168	3323	3801	2882	2182	1615	1	1
1	1969	1473	915	818	816	986	2406	3690	3948	5223	3352	2708	2608	1882	2	2
1	1970	1173	1141	823	640	626	*1900	2990	3030	4363	*3900	*2600	2061	1303	3	2
1	1971	1655	1146	795	545	472	780	2468	2282	2745	4534	4183	2127	1268	1	1
1	1972	1482	1423	700	533	423	1204	2964	4360	3256	2718	1843	1712	1636	1	1
1	1973	1031	686	527	527	*400	1408	1205	2830	3716	4128	3372	2417	1027	3	2
1	1974	1449	936	733	575	*600	1411	2563	1736	2764	4090	1999	1195	1175	1	1
1	1975	1008	936	633	452	437	530	814	1212	2809	3867	4473	2166	753	2	2
1	1976	1711	1412	859	564	641	3083	3181	2128	2734	2159	2053	2440	1697	1	1
1	1977	1039	809	866	653	633	2768	2287	2536	2500	1856	2154	1834	1449	3	2
1	1978	1229	973	1226	831	734	*1900	3390	2508	4195	3831	2628	1903	1361	2	2
1	1979								3511	5196	5044	2733	3327		3	2
1	1980	1758	1427	1177	864	600	*1900	2646	3118	3753	3505	2845	3078	1449	3	2
1	1981	1409	1991	1567	895	794	1900	3927	4919	4872	4392	2897	2115	2175	3	2
1	1982	1522	1105	929	617	563	*1500	*2600	3132	4679	7313	2462	1465	983	2	2
1	1983	814	699	751											2	2
1	1984														2	2
1	1985														1	1
1	1986														2	2
1	1987									1471	1759	1460	1564		3	2
1	1988		1605	1485			3460	2268	3109	3745	5090	2344	1601		4	3
1	1989	1444	1302				1712	1506	2458	3740	6461	3079	*2300		3	2
1	1990														4	3

continued

Usumacinta River, Chiapas, Mexico, Discharge in Cubic Meters per Second

Stn	*Year*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Grow*	*C4*	*C3*
2 = El Tigre																
2	1964						1244	3168	1743	2230	2012	1147	2326		2	2
2	1965	1476	804	565	396	345	760	2189	1834	2186	3965	3692	1762	1046	1	1
2	1966	1702	1086	1015	1081	853	2127	3326	2166	3957	3701	2180	1201	1669	3	2
2	1967	1123	1037	758	650	412	1098	2207	2375	1946	4705	2995	1469	1207	2	2
2	1968	1244	1026	646	492	572	2107	2329	2814	3160	3625	2543	2043	1404	1	1
2	1969	1274	746	690	673	945	2389	3695	3733	5031	2817	2432	2332	1768	2	2
2	1970	946	1029	616	946	507	907	2614	3036	4409	4296	3091	1956	1325	3	2
2	1971	1052	703	578	530	484	618	1627	2448	3531	3210	3204	1875	1005	1	1
2	1972	1427	1237	591	484	787	1438	7623	4719	3168	2731	1696	1645	2288	1	1
2	1973	873	593	439	446	510	973	1205	2507	3698	4810	8556	2303	943	3	2
2	1974	1423	787	680	491	507	1449	2535	1727	2838	4357	2066	1063	1200	1	1
2	1975	1045	970	563	490	366	506	760	1240	3124	4389	4311	1872	743	2	2
2	1976	1624	1210	711	447	579	2248	3485	2137	3296	2550	2346	2911	1555	1	1
2	1977	968	783	891	560	431	2129	2407	2649	2412	1792	1970	1887	1352	3	2
2	1978	1012	767	961	645	651	2206	3400	2498	4110	3751	2883	1045	1518	2	2
2	1979	1100	819	639	495	544	2334	3589	3885	5430	5147	2841	3154	1676	3	2
2	1980	1557	111	815	624	624	2311	2621	2997	2834	373	298	3177	1457	3	2
3 = El Cedro																
3	1965						268	668	464	758	1352	1147	512		1	1
3	1966	569	391	416	456	254	680	850	526	932	980	697	379	518	3	2
3	1967	373	308	230	218	110	347	820	690	544	1681	958	395	387	2	2
3	1968	379	323	228	153	198	669	636	740	919	1214	772	698	416	1	1
3	1969	411	260	263	220	457	957	1095	1013	1242	833	856	830	584	2	3

* = interpolated values in place of missing data

Boca Del Cerro, Chiapas, Mexico, Mean Precipitation in Millimeters per Day

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Grow*	*C4*	*C3*
1970	3.7	1.7	0.7	0.6	1.3	8.7	9.8	8.6	10.5	12.0	6.2	2.5	4.4	3	2
1971	0.1	1.2	4.6	0.5	0.9	3.3	6.4	9.3	9.6	4.2	7.9	1.4	3.3	1	1
1972	3.2	2.2	0.6	2.3	2.5	17.0	13.5	8.1	11.0	9.1	7.8	12.8	6.2	1	1
1973	1.7	1.0	0.1	1.9	4.8	2.8	6.9	10.2	9.5	9.4	8.9	4.0	4.8	3	2
1974	1.7	5.1	0.2	2.3	3.3	12.2	5.1	5.9	17.4	9.7	3.7	2.7	4.5	1	1
1975	3.9	2.7	1.3	0.1	5.5	5.2	6.7	4.7	5.8	14.8	5.0	2.1	3.8	2	2
1976	4.5	3.3	0.8	1.0	4.2	11.7	3.9	11.4	4.4	7.2	8.5	6.8	5.1	1	1
1977	3.1	3.8	2.5	0.8	2.1	6.7	5.1	7.5	13.1	4.0	6.3	5.4	4.0	3	2
1978	6.6	7.8	8.6	1.1	8.4	11.0	9.7	13.4	20.6	15.0	8.5	3.7	8.3	2	2
1979	4.0	1.9	1.2	5.8	2.7	16.0	6.5	10.7	21.5	5.1	7.5	10.7	6.1	3	2
1980	2.2	4.9	5.3	3.2	5.0	10.6	8.9	7.2	16.4	5.8	8.3	6.5	5.9	3	2
1981	0.7	5.5	6.2	4.4	7.3	14.2	8.8	14.7	17.5	11.3	1.5	2.9	7.7	3	2
1982	3.7	9.1	4.5	4.3	5.5	14.2	6.7	4.8	18.3	9.7	4.6	3.1	6.6	2	2
1983	1.9	1.9	0.9	1.3	0.9	8.8	9.6	7.5	12.8	8.8	7.5	12.0	4.1	4	3
1984	3.4	3.5	0.2	0.8	15.2	6.9	10.1	9.5	21.7	6.8	1.6	2.5	6.2	2	2
1985	3.6	1.7	1.8	2.6	5.9	4.7	9.0	3.6	13.1	6.9	2.4	11.1	4.1	1	1
1986	4.0	0.7	3.3	1.5	10.3	6.3	4.3	5.5	8.4	7.2	6.2	4.2	4.5	3	2
1987	1.4	3.3	2.5						7.0	10.2	3.6	5.1		3	2
1988	6.4	2.8	1.3	5.0	0.5	14.5	4.3	11.8	10.3	10.9	3.1	2.1	5.8	4	3
1989	4.4	4.4	1.9	2.8	7.0	3.6	2.5	3.3			8.0		3.7	3	2

APPENDIX 2. STATISTICAL TABLES FOR DISCHARGE AND PRECIPITATION.

Key

Grow—Growing season average monthly precipitation.

Boldface values statistically significant at the .05 level.

Solar Annual average international sunspot number to estimate rate of solar emissions.

ApTr Apparent transmission of the atmosphere, i.e., how much debris is in the upper atmosphere.

WSOI Winter Southern Oscillation Index to estimate the state of El Niño.

CO_2R Regression slope of carbon dioxide increase in the atmosphere.

CO_2T Trend in the increase of carbon dioxide in the atmosphere.

$AdjR^2$ Adjusted R^2

F F-value for the multiple regression equation.

p probability of the R^2 being due to random circumstances.

Candelaria at Candelaria, 31 years, 1958–1990

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Grow*
ANOVA Climate (C4) NHTT (850-300 mb) vs. Discharge													
R	0.65	0.63	0.62	0.63	0.49	0.54	0.47	0.52	0.44	0.46	0.38	0.43	0.67
R^2	0.42	0.39	0.39	0.40	0.24	0.30	0.22	0.27	0.19	0.21	0.14	0.18	0.45
F	6.54	5.84	5.71	5.98	2.78	3.78	2.56	3.27	2.16	2.38	1.47	1.99	7.47
p	**0.002**	**0.003**	**0.004**	**0.003**	0.061	**0.022**	0.076	**0.037**	0.116	0.092	0.245	0.140	**0.001**
ANOVA Climate (C3) NHTT (850-300 mb) vs. Discharge													
R	0.65	0.63	0.62	0.62	0.48	0.54	0.47	0.50	0.41	0.31	0.31	0.37	0.67
R^2	0.42	0.39	0.39	0.39	0.23	0.29	0.22	0.25	0.17	0.09	0.10	0.14	0.45
F	10.12	9.08	8.81	8.90	4.11	5.81	3.97	4.72	2.78	1.46	1.49	2.27	11.43
p	**<.001**	**0.001**	**0.001**	**0.001**	**0.027**	**0.008**	**0.030**	**0.17**	0.080	0.250	0.244	0.122	**<.001**
Multiple Regression Discharge vs. Influencing Variables													
Standard Coefficients													
Solar	**0.47**	**0.48**	**0.42**	**0.43**	**0.43**	**0.61**	**0.51**	**0.47**	0.28	0.13	0.28	0.39	**0.60**
ApTr	–0.37	–0.50	–0.41	–0.45	–0.60	–0.14	–0.06	0.09	0.00	–0.21	–0.34	–0.38	–0.29
WSOI	0.07	0.10	0.15	0.17	0.23	0.006	0.02	–0.03	0.19	0.22	0.26	0.17	0.08
CO_2R	0.32	0.33	**0.42**	**0.44**	**0.43**	0.20	0.08	0.00	0.16	0.18	0.22	0.19	0.27
CO_2T	0.39	0.28	0.34	0.29	0.08	0.11	0.23	0.34	**0.55**	**0.43**	**0.42**	**0.44**	0.34
R	0.77	0.77	0.76	0.77	0.73	0.68	0.58	0.62	0.65	0.51	0.60	0.68	0.79
R^2	0.60	0.59	0.58	0.59	0.53	0.46	0.34	0.38	0.42	0.26	0.36	0.47	0.63
AdjR^2	0.52	0.51	0.49	0.51	0.44	0.36	0.21	0.26	0.30	0.11	0.23	0.36	0.55
F	7.47	7.19	6.84	7.12	5.74	4.32	2.58	3.07	3.61	1.75	2.84	4.37	8.42
p	**<.001**	**<.001**	**<.001**	**<.001**	**0.001**	**0.006**	0.052	**0.027**	**0.014**	0.158	**0.036**	**0.005**	**<.001**

Champotón at Canasayab, 25 years, 1958–1986 (1977, 1978, and 1984 eliminated as outliers)

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Grow*
ANOVA Climate (C4) NHTT (850-300 b) vs. Discharge													
R	0.27	0.27	0.22	0.32	0.32	0.45	0.42	0.40	0.28	0.57	0.27	0.38	0.43
R^2	0.07	0.07	0.05	0.10	0.10	0.21	0.18	0.16	0.08	0.32	0.07	0.14	0.18
F	0.54	0.53	0.36	0.81	0.78	1.82	1.53	1.33	0.60	3.34	0.54	1.09	1.58
p	0.660	0.667	0.783	0.504	0.517	0.174	0.235	0.292	0.621	0.039	0.662	0.375	0.224
ANOVA Climate (C3) NHTT(850-300 mb) vs. Discharge													
R	0.18	0.19	0.18	0.25	0.32	0.45	0.42	0.38	0.28	0.46	0.25	0.36	0.43
R^2	0.03	0.04	0.03	0.06	0.1	0.21	0.18	0.15	0.08	0.21	0.06	0.13	0.18
F	0.36	0.41	0.35	0.71	1.22	2.83	2.40	1.86	0.95	3.00	0.71	1.66	2.48
p	0.704	0.667	0.709	0.502	0.320	0.080	0.115	0.180	0.400	0.070	0.503	0.214	0.107
Multiple Regression Discharge vs. Influencing Variables													
Standard Coefficients													
Solar	–0.01	–0.02	–0.08	0.14	–0.10	0.22	0.21	–0.25	0.26	0.05	**0.41**	0.09	–0.08
ApTr	0.19	0.07	0.17	0.16	–0.09	–0.13	–0.10	–0.02	–0.15	0.12	0.00	–0.14	0.00
WSOI	–0.34	–0.29	–0.29	–0.50	–0.09	0.00	–0.02	–0.07	0.27	–0.13	0.06	0.08	–0.17
CO_2R	–0.11	–0.18	–0.29	–0.25	0.22	–0.17	–0.37	0.04	–0.04	–0.35	–0.16	–0.16	–0.11
CO_2	**0.78**	**0.72**	**0.73**	**0.57**	**0.65**	0.22	0.15	0.33	0.30	0.07	0.30	**0.71**	**0.57**
R	0.84	0.84	0.89	0.80	0.66	0.39	0.47	0.43	0.40	0.35	0.51	0.84	0.67
R^2	0.70	0.71	0.79	0.63	0.43	0.15	0.22	0.19	0.16	0.13	0.26	0.70	0.45
$AdjR^2$	0.63	0.63	0.73	0.54	0.28	0.00	0.02	0.00	0.00	0.00	0.06	0.62	0.30
F	9.07	9.10	14.28	6.55	2.88	0.67	1.10	0.88	0.73	0.55	1.31	8.78	3.10
p	**<.001**	**<.001**	**<.001**	**0.001**	**0.042**	0.649	0.393	0.512	0.607	0.739	0.301	**<.001**	**0.033**

Usumacinta at Boca del Cerro, 25 years, 1958–1982

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Grow*
ANOVA Climate (C4) NHTT (850-300 mb) vs. Discharge													
R	0.49	0.46	0.31	0.46	0.39	0.41	0.10	0.28	0.52	0.41	0.27	0.08	0.32
R^2	0.24	0.21	0.10	0.21	0.15	0.17	0.01	0.08	0.27	0.17	0.08	0.01	0.10
F	2.10	0.81	0.73	1.79	1.17	1.36	0.07	0.57	2.41	0.13	0.24	0.05	0.74
p	0.133	0.180	0.550	0.182	0.345	0.285	0.976	0.644	0.097	0.290	0.663	0.987	0.543
ANOVA Climate (C3) NHTT (850-300 mb) vs. Discharge													
R	0.45	0.37	0.23	0.34	0.29	0.25	0.08	0.14	0.51	0.35	0.27	0.07	0.07
R^2	0.20	0.13	0.05	0.11	0.08	0.06	0.01	0.02	0.26	0.12	0.07	0.00	0.01
F	2.61	1.61	0.59	1.33	0.93	0.69	0.07	0.22	0.37	1.43	0.81	0.051	0.05
p	0.098	0.223	0.564	0.286	0.409	0.515	0.930	0.802	0.042	0.262	0.460	0.956	0.950
Multiple Regression Discharge vs. Influencing Variables													
Standard Coefficients													
Solar	0.28	0.35	0.33	0.18	0.39	0.37	0.37	**0.54**	0.15	0.20	–0.27	0.23	**0.54**
ApTr	–0.07	0.14	0.14	0.12	0.16	0.23	–0.01	0.06	–0.13	–0.64	0.45	0.19	0.12
WSOI	0.18	0.29	–0.01	0.07	–0.09	–0.06	–0.01	–0.03	–0.21	0.12	–0.07	–0.36	0.02
XO_2P	–0.34	–0.21	0.09	0.00	–0.02	–0.04	–0.24	–0.12	0.10	–0.13	0.33	**0.40**	–0.18
XO_2T	0.02	0.29	**0.56**	0.11	0.04	0.16	–0.04	0.29	**0.51**	0.08	0.02	0.17	0.23
R	0.43	0.57	0.58	0.25	0.45	0.44	0.35	0.61	0.56	0.74	0.31	0.61	0.58
R^2	0.18	0.32	0.34	0.06	0.20	0.19	0.13	0.38	0.32	0.55	0.10	0.37	0.34
$AdjR^2$	0.00	0.13	0.15	0.00	0.00	0.00	0.00	0.20	0.13	0.42	0.00	0.20	0.15
F	0.79	1.70	1.83	0.24	0.89	0.86	0.51	2.18	1.68	4.31	0.39	2.14	1.83
p	0.569	0.186	0.158	0.940	0.505	0.529	0.760	0.102	0.190	**0.009**	0.851	0.107	0.158

Usumacinta at Boca del Cerro, Precipitation Statistics, 20 years, 1970–1989

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Grow*
ANOVA Climate (C4) NHTT(850-300 mb) vs. Precipitation													
R	0.45	0.55	0.36	0.34	0.65	0.21	0.25	0.22	0.38	0.51	0.23	0.43	0.41
R^2	0.20	0.31	0.13	0.12	0.42	0.04	0.06	0.05	0.15	0.26	0.05	0.18	0.17
F	1.33	2.35	0.80	0.67	3.66	0.22	0.33	0.26	0.85	1.74	0.29	1.11	1.01
p	0.301	0.111	0.511	0.582	**0.037**	0.878	0.801	0.853	0.488	0.202	0.834	0.375	0.417
ANOVA Climate (C3) NHTT (850-300 mb) vs. Precipitation													
R	0.26	0.28	0.32	0.24	0.53	0.20	0.08	0.17	0.28	0.28	0.08	0.35	0.28
R^2	0.07	0.08	0.10	0.06	0.28	0.04	0.00	0.03	0.08	0.08	0.01	0.12	0.08
F	0.61	0.75	0.97	0.50	3.15	0.33	0.05	0.25	0.67	0.70	0.06	1.12	0.69
p	0.555	0.489	0.398	0.614	0.070	0.726	0.953	0.785	0.528	0.511	0.941	0.350	0.517
Multiple Regression Precipitation vs. Influencing Variables													
Standard Coefficients													
Solar	0.05	0.36	**0.44**	**0.58**	–0.17	**0.48**	0.15	0.13	**0.57**	–0.04	0.24	0.01	0.47
ApTr	0.08	–0.39	0.04	–0.10	0.06	–0.12	–0.10	0.24	–0.10	–0.10	0.12	0.03	–0.04
WSOI	0.01	0.19	–0.10	0.18	0.11	0.08	–0.47	–0.35	0.11	–0.37	–0.17	–0.33	–0.13
CO_2R	–0.24	–0.49	–0.67	–0.04	–0.38	–0.57	–0.23	0.23	–0.20	0.05	–0.08	–0.56	–0.60
CO_2T	**0.49**	**0.46**	**0.57**	0.33	**0.78**	0.32	–0.25	–0.49	0.30	–0.24	–0.39	**0.40**	**0.47**
R	0.31	0.66	0.54	0.73	0.53	0.56	0.61	0.55	0.62	0.36	0.50	0.42	0.57
R^2	0.10	0.44	0.29	0.54	0.28	0.32	0.37	0.30	0.38	0.13	0.25	0.18	0.33
$AdjR^2$	0.00	0.24	0.04	0.36	0.00	0.05	0.13	0.03	0.15	0.00	0.00	0.00	0.07
F	0.31	2.19	1.14	3.03	1.01	1.21	1.55	1.11	1.62	0.40	0.94	0.56	1.26
p	0.902	0.114	0.386	**0.050**	0.452	0.360	0.242	0.403	0.224	0.843	0.490	0.731	0.338

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Chapter 10

The Lowland Maya Civilization: Historical Consciousness and Environment

David Freidel and Justine Shaw

The lowland Maya civilization occupied a territory in southern Mexico and Central America about the size of New Mexico in the United States.[1] The environment is broadly characterized as a tropical rainforest on the karstic limestone base of the Yucatan peninsula, but both the ecology and geology are considerably more complex. The Maya are as famous for the collapse of a large portion of their civilization in the ninth century A.D. as they are for their achievements in art, architecture, mathematics, astronomy, and writing. The ancient Maya perception and interpretation of their environments, social and natural, is just beginning to play a significant role in modern scholars' analysis of that society's adaptive successes and failures over the long term. One new source of evidence is the ongoing decipherment of Maya texts of the Classic period.[2]

The record of this civilization is rich, complex, fragmentary, and controversial. The record of the natural environment is likewise rich and controversial. Don Rice (1993) provides an excellent recent summary of physical geography in the region and the issues surrounding its interpretation.

Kent Flannery and Joyce Marcus wrote a seminal article on the Zapotec people of the Valley of Oaxaca, articulating the idea that the way Mesoamericans conceived of their climate and natural environment was a vital clue to long-term adaptation.[3] An important feature of their argument, following the theoretical thinking of Roy Rappaport (1971), was that the ancient Zapotecs ritually expressed their roles in the management of strategic environmental variables, encoding historical observations about ecological relationships in a theory of social and natural reproduction. These rituals in turn have left identifiable artifactual remains and depositional patterns in the long-term archaeological record. We attempt to explore these productive ideas in the context of lowland Maya civilization. Our approach is basically two-pronged, reflecting two distinct but connected research strategies. Both

of these focus on what the Maya themselves identified as important in their relationship to their environment and climatic variability, that is to say, historical consciousness. First, we consider what the Maya stated, in their ancient texts and cosmology, that might shed light on their own views of the environment and climate. We follow the work of Victoria Bricker (1981) and Gary Gossen (1986), among others, in proposing that the Maya encoded their historical consciousness in public ritual performance and in records of such performance. We hypothesize on that basis that ancient Maya kings had important roles in community rituals and other actions responding to environmental dynamics, displaying historical theories concerning them. Second, we compile some statistical information on contemporary Maya rituals and farming practices to test a related hypothesis that the colonial and modern descendants of those royal constituencies still respond ritually to variation in environment and climate. Finally, we offer some broad speculations as to how Classic Maya governments may have functioned, or failed to function, to reduce the risks of social catastrophe resulting from long-term environmental fluctuations. We begin with consideration of Maya concepts of history, an essential feature of historical consciousness.

Linear and Cyclical Maya History

Maya people have kept count of days, and the cyclical patterns that days and nights reveal, from at least A.D. 200 to the present, beginning the written record on perishable materials and probably keeping oral accounts much earlier. A historical ecology of the Maya should begin with their comprehension of time, that fundamental feature of the environment. The cultural definition of time is crucial to understanding what the Maya recorded in the past about their environment, both natural and social, and to understanding how these people responded to phenomena in their environment. The great Mayanist and naturalist Dennis Puleston (1979) once proposed that the Classic Maya collapse in the ninth century A.D. was in part due to expectations among leaders of an inevitable dark age that had been predicted by their cyclical notions of historical causality. While Puleston was probably off the mark in the particular, his tying of royal policy to a time-driven theory of history will likely prove prescient.

Anciently, the Maya sense of time was formally fixed in the counting of days or, better, nights, for nights revealed the celestial patterns central to Maya cosmology. They counted days in cycles so great that, for most historical intents and purposes, they constituted linear time. The Maya "Long Count" anchored into the end of the last creation and the beginning of the present one on 13 August 3114 B.C. By A.D. O, they wrote as they counted, encoding their observations of nature and history in true written language and in texts that became relatively abundant between A.D. 300 and A.D. 900. The Maya accounting of events during this era is the most precise in ancient

history, for things worth noting were recorded to the day (or half-day). After A.D. 900, when the Maya left us writings tied to cycles of time in the books of *Chilam Balam* (Jaguar Prophet) of Yucatan, events were not anchored to creation day but bound only to their particular *katun* (7,200-day cycle), as designated by which of thirteen numbered days of *Ahaw* (Lordship) in the sacred 260-day round begins the katun. The numbered days of Ahaw permutate in such fashion that the same-numbered Ahaw day will begin the katun every 256 years, or round of thirteen katuns. This is the so-called Short Count, and it is a cyclical reckoning of history. While the books of Chilam Balam include entries that show they were still being written well into the colonial period, they make reference to preconquest events and evidently constitute a tradition in prophetic chronicle spanning the contact period. In particular, prophecy focused on environmental catastrophe such as drought and famine.

The distinction between the Short Count and the Long Count as a perception of time is fundamental and still a matter of strategic confusion for some scholars of the Maya. Again, during the Classic period (ca. A.D. 200–900), the Maya of the southern lowlands (about 80,000 square kilometers, or 48,000 square miles) kept historical records in the Long Count. While we know that the sages doing the writing made reference to the day that initiated this creation and to other mythologically important events and dates, they also shared a sense of chronicle that we identify with our linear conception of time. Some influential Mayanists still insist on extrapolating the Short Count sense of cyclical time operative in conquest-period Yucatan back to the Classic Maya of the first millennium A.D. This is an application of the direct historical approach, long honored and accepted as a method among Mayanists but no longer impervious to empirical challenge by independent evidence.

With the tumult of the ninth century, Maya historical consciousness passed from a linear to a cyclical mode. The subject matter of the katun histories of Yucatan includes natural disasters—drought, hurricane, epidemic disease—and their spawn, famine and migration. These cyclical accounts also include descriptions of wars, alliances, accessions, marriages, and the affairs of states and their nobility. Linda Schele (Schele, Grube, and Boot n.d.) thought she could document that some eighth- and ninth-century historical events and personages were transposed to later seatings of the same katun, that is, moved 256 or 512 years forward in time. For example, the famous Mesoamerican culture hero Kukulkan (Quetzalcoatl in Nahuatl) is described in the Chilam Balam katun histories in a manner suggesting that he manifested in the tenth-century heyday of Chichen Itza, but the legends of this man place him in the seventh century. Ralph Roys (1967:161) concluded that there were probably several Kukulkans, but transposition is another good prospect now. The value in this prospect is that what we have heretofore taken to be a mythological Mexican culture hero with a possible human avatar at the apex of Chichen Itza's power may instead have been a gen-

uinely historical lowland Maya king who lived at the time of Chichen Itza's establishment, as implied by the katun histories.

It is tempting to use the subject matter of the Yucatecan katun histories to discern the historical interests in the social and natural environments of the earlier Classic period (A.D. 200–900). On the one hand, there are real parallels. The Classic period texts remark on state affairs and events in the lives of aristocracy: wars, alliances, births, accessions, deaths, marriages, and so forth. On the other hand, epigraphers have yet to find clear statements about such important natural events as drought and epidemic diseases or about migration, abandonment, and famine, all of which figure prominently in the katun histories of Chilam Balam. One must be cautious with such negative evidence, for several times in the process of Maya textual decipherment scholars have concluded that some subjects were not recorded, only to discover that they were indeed there. The case of warfare is a dramatic current example.[4]

There is potential, then, to find in what the Classic Maya elite said about their world a record of their views of the natural environment and its relationships to the social order. The challenges are formidable, however. In the first place, if the Maya scribes were talking about such things in a clear code akin to our terms, we would already probably know about it. The alternative is that they wrote about such matters as subsistence agriculture, weather, and disease in more oblique and metaphorical terms. The metaphors of Maya royal and elite rhetoric are primarily and manifestly religious. Some scholars have made the mistake of supposing that because the supernatural and the mythical pervade Classic elite discourse, it only talks about esoterica of no practical consequence to the sustaining populace in the cities and countryside. This again reflects the error of deciding what the Maya scribes were not talking about based on our own ignorance rather than on certain understanding.

The lesson to be learned is that we are just beginning to comprehend the Maya textual record. Trying to anticipate where we might go with both the Maya view of their environment and our own, we are sifting through their metaphors for clues to future empirical patterns. First, the role of the speaker or observer in Maya texts must be considered.

We hold the position that Maya rulers and their principal scribes were essentially shamans, adepts in magical power acquired through personal experience in the supernatural otherworld. We call the Maya kings shamans not only because of their manifest interest and performances in the supernatural world but because the many images and symbols of Maya religion correspond very well to shamanic traditions recorded throughout the Americas and the Far East. Whether or not the particulars of the shamanic hypothesis hold, the general proposition is so far productive.[5] We propose that in the Maya view of the Classic period, the political leaders were personally responsible for the physical well-being of their people in the manner in which shamans are responsible for the well-being of their communities. If we are right, then Classic Maya elite performances should reflect concern for

aspects of the ambient environment that are traditionally the domain of shamans, such as disease and the prosperity of the crops, along with skill in witchcraft, attack magic, and its shields as necessary to prosecute war.

Kings as Companions of Death and Disease

Disease is one challenging issue. There is a wealth of potential and recorded data on contemporary Maya shamanic practice with respect to disease, but the past is more problematic. One important colonial source, the Princeton Codex, commonly called the *Ritual of the Bacabs* and probably written down in the eighteenth century in Yucatan, was translated into English by Ralph Roys (1965), who suggests that, judging by the language used, the manuscript he saw was likely a copy of one much older. In this unique compilation of incantations, the speaker conjures up personified diseases, controls them through specific knowledge of their birth, location, and symbols, and then condemns them back to the otherworld through a variety of metaphorical means, including decapitation, dismemberment, and other sacrificial practices. The procedures used to conjure up the diseases involve the formal fixing of the space into which the disease being manifests as a four-quartered, or quadripartite, one marked by colors, trees, birds, and world-bearer gods. This establishment of fixed space is fundamental to contemporary Maya shamanic practice and was definitely featured in the ritual conjuring of supernaturals and ancestors by Classic Maya nobility. Freidel, Schele, and Parker outlined the case for continuity in such spatial conceptions in *Maya Cosmos* (1993). The Ritual of the Bacabs also contains direct references to many important deities of the Classic period, including Hun Ahaw, the maize god, also called First Father (or First Born of the Ancestral Hero Twins); Ix Chel (called Chak Chel in the Classic period), a principal female divinity responsible for witchcraft, childbirth, and weaving and the patroness of shamans; the Pawahtuns, the world bearers; and of course the Bacabs.

The Ritual of the Bacabs manuscript was written in Yucatec Maya, as were the books of Chilam Balam, the Jaguar Prophet. The history of the manuscript is a mystery, but it contains no allusion to Spanish friars or other evidence that it was a solicited oral history. The translator and great ethnohistorian Ralph Roys and his colleague J. Eric Thompson believed that the references to divinities and animal spirits, the cosmological content, and the organization of the manuscript suggested that it reflected interests found in the three known Maya codex books written before the conquest.[6] In light of recent decipherment, we think they were correct in this supposition and that the original copy of the Ritual of the Bacabs was, like some early entries in the books of Chilam Balam, a transliteration from the glyphic.[7] Generally, the content of this manuscript confirms that members of the literate elite in the colonial period, and back to the time of the conquest, included adepts in curing illness.[8] More importantly, it clarifies that they confronted personified diseases in order to exorcise them.[9]

Personification is, we think, a potential metaphorical key to the Classic Maya perspective on disease and affliction viewed more generally, including drought and famine. Some certainties encourage this view. Firstly, Classic Maya kings and high nobility were indeed conjurers of personified beings, and they carried out conjuring in fixed ritual spaces and in sanctified huts directly analogous to those described in the Ritual of the Bacabs (see ch. 3 of Freidel, Schele, and Parker 1993). The beings conjured up by Classic elite were many and diverse, including creator gods, war gods, ancestors, vision snakes, and a variety of beings called *way*. Some of the original discoverers of this term deciphered it as "spiritual co-essence," and this makes good sense (see Houston and Stuart 1989). Nikolai Grube and Werner Nahm have recently inventoried the Classic Maya *wayob*, especially as portrayed in rituals on painted vessels (see Houston and Stuart 1989). Among the wayob beings are several who clearly represent death- and, we would suggest, disease-related ones.[10]

The connection between personified deathly beings and personified diseases is explicitly given in the Book of Council of the K'iche' Maya of highland Guatemala, the Popol Vuh. The Popol Vuh is a colonial-period document recounting the creation and the subsequent history of the K'iche' nation. The parallels between the Popol Vuh account of creation and that left to us in Classic-period texts are so clear that several scholars regard the Popol Vuh as a redaction of the broadly shared Classic Maya creation myth cycle.[11] Indeed *Maya Cosmos* (Freidel, Schele, and Parker 1993) is to a large extent an exploration of that hypothesis and its implications for archaeology.

In the Popol Vuh story, the ancestral creators of human beings, First Father, First Mother, and the Hero Twins, contest with the death lords of Xibalba, the otherworld, and defeat them. The death lords are named after diseases, filth, and violent sacrificial acts. As Schele, Freidel, and Parker described in *Maya Cosmos*, Classic Maya elite, especially kings, publicly performed as these ancestral gods and in so doing confronted death lords like those described in the Popol Vuh.

Even at this tentative level of contemplation, the potential Classic Maya views of disease and affliction are complex and ambiguous, for, on the one hand, we have evidence of rulers conjuring up death- and disease-related beings as spirit companions; on the other, we have them confronting such beings and triumphing over them. On reflection, however, that combination of connection and command is what the incantations in the Ritual of the Bacabs actually imply with their recitations of parentage, and sexual metaphors of procreation and birth in the conjuring processes, and the peremptory demands the shaman places on both personified diseases and helpful beings like Bacabs. If we are on the right track, then the many painted scenes on vessels depicting dancing and performing wayob of elite may represent the Maya elite's contemplation and exorcism of physical scourges afflicting the populace. A further implication would be that a potential source of disease was human sorcery perpetrated by rulers and members of

the elite through their disease spirit companions. Finally, a view of disease that placed human rulers in the center of causation and healing in their domains could have had significant repercussions on the formation and maintenance of alliances between domains and the prosecution of wars between them. This would be especially important during periods of general discord, environmental stress, population movement, and increased opportunity for epidemic disease.[12]

Gods and Rulers as Forces of History

Just as disease is a subject of clear interest to the writers of the Chilam Balam katun histories but not a transparent subject in Classic historical consciousness, so crop failure and famine stemming from drought and insect plagues figure in the colonial katun histories but not obviously in Classic texts. The katuns themselves are personified and divine in the Chilam Balam books, and they are also associated with other deities, who serve as their faces. Sometimes there is no obvious correlation between the nature of a given god and the prophecy for the katun. For example, katun 11, Ahaw, a time of drought and famine, is presided over by Yax-haal Chak, the Green Water rain god, or rain god of the center. The ruler of katun 3, Ahaw, however, is Bolonti-Ku, a dread god suitable to preside over this katun of famine and misery. On a more practical level, passages in the Chilam Balam books clearly tie the greed, immorality, profanity, and ritual ignorance of rulers to drought, pestilence, and famine. The consequence of drought and famine for such rulers, in one case, is interrogation for failure in ritual knowledge and evidently sacrifice on posts or scaffolding in a public place (see Roys 1967:102–103). In other cases, rulers are brought down by war in famine-stricken katuns. The other side of this contingency between environment and government also holds, namely, when rulers governed well, there was prosperity and health in their dominions.

There is reason to believe, then, that Maya rulers of the contact period were held responsible through their conduct and ritual knowledge for the manner in which the weather and crop-related prophecies of the katuns unfolded. Projecting this responsibility backward to the Classic period offers more of a framework than obvious parallels. The framework is the intense and pervasive interest in the katuns and other temporal cycles displayed in Classic texts. Even when events in the lives of rulers—such as birth, accession, or capture—are foregrounded, they are often tied into the endings of major periods like the katun, the *lahuntun* (half-katun), or *ho-tun* (quarter katun). Drought, pests, and famine, however, do not figure into current decipherments of public texts.

What we do find revealed in the monumental texts and related images is that Classic Maya rulers and elite regularly conjured up divinities and ancestors, both to commune with and to embody. The capacity of Maya

kings to do this in conjunction with major historical events such as birth, death, accession, marriage, victory in war, and celebration of the period endings (especially the katun) must be linked to Classic ritual and mystical obligations registered as good governance. Among the gods that the Classic Maya kings manifested commonly were Chak, the rain god; Itzam-Yeh, the Magic Bird, source of prosperity; and Hun-Nal-Yeh, One-Maize (kernel)-Revealed, the first father and symbol of maize, the principal Maya food. As previously discussed in the previous section, Maya kings and nobility could also manifest as death gods and conjure up terrible war gods.

So, even more than the kings and nobility of the contact period, the Classic royalty were quite literally divine beings in themselves, called Holy Lords. It seems possible to us that the principal gods of the temporal cycles in the Classic period were ensouled in these human beings, each major dynasty defining through such manifestations the prophetic history of its realm, the link between the past and the future. Schele and Freidel deconstructed Maya history and historical consciousness in *A Forest of Kings* (1990) in ways that try to reveal the practical political intentions of the rulers. Classic Maya history, however, was much more than royal propaganda bolstering the power of monarchs and elite. We postulate that it also constituted revealed truth connected in a manner perceived as causal to the social and natural events of the kingdoms. That is, Maya kings, in conjunction with state gods identified with the capitals, performed prophetic history as gods in the Classic period.[13] In these glyphic histories of realms, through the metaphors of the individual ruler, we must look for the repercussions of the natural and social worlds.

Classic kings essentially undertook two kinds of performances that reflect on their construction of history: (1) performances of alliance formation and war that confirmed power over the deadly supernaturals responsible for disease, drought, famine, and other afflictions; and (2) performances of creation-era events that revealed command of the forces of prosperity, health, and agricultural abundance (we have briefly alluded to the first category). Without going into details here, we can report that Maya political alliances are robustly documented for the Classic period. There were two major powers, hierarchical and led by the cities that we call Tikal (knot of hair) and Calakmul (snake), that fought wars throughout the Classic period (A.D. 378 to ca. A.D. 820). Virtually all major southern lowland Maya kingdoms of the Classic period were engaged in the struggle, which we call the Alliance Wars.[14] We speculate that enemies, well known to each other, were regarded as sources of evil, drought, disease, and insect plague, as their rulers incarnated war gods and wayob capable of inflicting sorcerous harm. It is not speculation that Classic Maya rulers, like their shaman counterparts in Ritual of the Bacabs, were personally required to confront such enemies on the field of battle and paid the price in capture, torture, and sacrifice when they lost. In our ethnocentrism, we are sometimes inclined to view as simple sadomasochistic ritual procedures that to the performers must have represented the deactivation of extremely dangerous forces. The Classic Maya

attitude toward the supernatural power of enemies is confirmed in the manner in which victors carefully desecrated the temples, council houses, and tombs in enemy ceremonial centers. This is a major new pattern in the archaeological record that we are just beginning to discern and define.

From an outside vantage, the alliances between dynasties of holy lords that persisted throughout the Classic period likely served to provide not only security but also the trade, gifts, and risk-reducing support that offset natural perturbations in food supply and social afflictions. Ethnohistory confirms that famine in Mesoamerica spurred both trade and conquest.[15] From the vantage of the Maya nobility, the celebrations accompanying alliances were opportunities for peers to witness and confirm the right conduct and spiritual power of allies before their populations. The production of the extraordinary and aesthetically brilliant settings and instruments in Maya architecture and art for such performances should be attributed not to some simple obsession with luxury but rather to a genuine concern that the supernatural collaborators in these events be appropriately impressed and respond accordingly in real-world terms. In this perspective, the alliances of the Classic Maya, with their roots in the original Pre-Classic farming communities and their branches in the complex trade of the contact Maya, were the fundamental adaptive strategy fostering success in this environment (see Freidel 1979).

For some time, archaeologists have pondered the patterns of Maya architectural construction and art production relative to the ninth-century collapse of the southern lowland kingdoms. It seemed as if the Maya rulers were desperately trying to make their covenants with supernatural powers more effective by means of grander and more elaborate rituals, a strategy doomed to failure if the problems were due to stress in the agricultural system caused by overdemand or degrading soils. We do not doubt that there was stress in the Maya relationship to the natural environment in the eighth century; this has been empirically documented in some, though not all, parts of the lowlands (see Rice 1993). But given that population densities were high throughout the lowlands in Late Classic times, we suggest that the ninth-century collapse must be ultimately attributed to failed social institutions rather than failed agricultural strategies: the states of the northern lowlands prospered in this same century, and that is a much more marginal environment for maize farmers. If the key social institutions were the alliances binding polities into regional networks, then it follows that the alliances failed. We think we are close to having the empirical means, through the identification of ritual destruction levels in Maya sites, to test the proposition that the alliances failed because they gradually generated an all-consuming obsession with war.[16] In our own recent thinking about this evident obsession, we have tended to emphasize the hubris of individuals and families pursuing deadly dynastic feuds over centuries. Compounding that view is the notion presented here that political enemies were a primary source of natural affliction through supernatural means and that leaders were required to confront and conquer them to alleviate such affliction. The maintenance of the alliances

capable of fighting successful wars might well have spurred the production of the architecture and goods necessary to the great ceremonial occasions in which alliances were forged, celebrated, and confirmed. Not only would such occasions have called for the redistribution of wealth within and between realms, but they would also have displayed the principals' supernatural power and right conduct to their constituencies.

In such a perspective, then, perhaps the best evidence we can find of the Maya's historical awareness of and response to environmental stress among the southern lowland Classic-period elite is in their performance of their duties as supernaturals. On the one hand, they strived to generate prosperity through communication with gods and ancestors and by the rituals of death and resurrection in the cosmic cycle that drove the agricultural cycle. They invited the participation of their allies in such work. On the other hand, they attacked their human enemies and, through them, their supernatural ones. In this way, among other things, they worked to alleviate afflictions, such as drought, pestilence, and famine.

As a strategy, warfare was as old as civilization itself among the lowland Maya. Its catastrophic failure as a strategy in the ninth century suggests that just as alliance through commerce and redistribution could even out the variable risks and perturbations of the natural environment for farming populations, so through war it could spread the destructive consequences of such perturbations. If the environmental conditions were sufficiently severe in even part of the lowland region, then perhaps the escalation of war to political collapse would follow. To suggest somehow that the relationship is causal, however, is to miss the point, for undoubtedly environmental stress could be attributed in part to centuries of conflict disrupting or constraining effective agricultural strategies and redistribution networks. The point, rather, is that the Maya kings and elite were necessarily responding to their circumstances through their own historical consciousness rather than ours. Moreover they were not helpless pawns of a history that unfolded irrespective of their decisions but rather active participants in the shaping of that history. In this regard, we must accept their own premise that they mattered to the system. In order to explain what happened to them, in crisis and otherwise, we need to see their environment through their eyes. In the meantime, we can understand some of the relationship between the ritual responsibility of Maya leaders and environmental dynamics through other categories of data and other methods.

Maya Agricultural Rituals and the Environment

In general, societies like those developed by the Maya are clearly shaped not only by the character of the resources available on a regular basis but also by the predictability and regularity of their environments. In order to survive, agrarian societies must be able to foresee, to some degree, what strategies

will be necessary in the future based on what they have experienced in the past. It is not always possible, however, to predict reliably certain aspects of the climate and hence the prosperity of vital crops. It seems reasonable to expect that in locales where variable climate affects subsistence and survival, societies will adopt some means to deal with this variability. As we have seen, Maya people generally believed in an effective integration of spiritual and natural phenomena. Among Maya agriculturalists, strategies to grapple with uncertainty might range in principle from planting a wider variety of crops or plots in order to increase the chance that bad weather or disease would not wipe out the entire harvest, to increasing the investment in ritual activities in an attempt to appease the supernatural forces believed to control aspects of the environment. Here we examine relationships between rituals and environmental conditions we think are associated with agricultural production. Our hypothesis contends that the type and scale of rituals practiced by the Maya should relate directly to environmental quality and predictability. Those Maya groups living in regions where agriculture was a risky activity should be found to put more time, energy, and resources into ritual activity. Conversely, where more favorable agricultural conditions existed, one would expect to find a comparatively smaller investment or a shift in ritual focus to other interests. Ritual investment, in our view, should be linked to agricultural risk and thus should provide an institutional basis for coordinated agricultural and social investment in response to risk.

Our data set to evaluate these ideas consisted of forty-three Maya ethnographic and ethnohistoric cases gathered from contact period informants, historic documents, archaeological evidence, and modern ethnographies (see Annis 1987; Berlin, Breedlove, and Raven 1974; Bunzel 1952; Cancian 1965; Carmack 1973, 1976, 1986; Chase 1985; Clendinnen 1987; Colby and Colby 1981; Colby and Van Den Berghe 1969; Farriss 1986; Gann 1918; Gillin 1951; Gosner 1992; Gossen 1974; Hinshaw 1975; Jones 1986, 1989; LaFarge and Byers 1931; Lothrop 1933; Mackie 1924; McBryde 1945; Mendez et al. 1921; J. Nash 1970; M. Nash 1958; Oakes 1951a, 1951b; Orellana 1984; Pagden 1971, 1975; Perera and Bruce 1982; Press 1975; Redfield and Villa Rojas 1939, 1962; Roys 1933, 1939, 1943, 1949; Rumney and Oliver 1987; Scholes and Roys 1968; Schwartz 1990; Steggerda 1941; Stevens 1964; Tax 1953; Tedlock 1985; D. Thompson 1960; J. Thompson 1939, 1970; Tozzer 1966; Tumin 1952; Villa Rojas 1945; Vogt 1969, 1990, 1993; Wagley 1949, 1969; Wagner 1964; Watanabe 1992; Wernstedt 1972; Wilk 1991; and Wilson 1980). Although the dates represented by these cases (see appendix 10.1) range historically from about A.D. 1400 to 1994, we passed over these temporal differences on the grounds that each case represented a particular ethnographic moment. Focusing synchronically on the society at the time of description, as reflected in its rituals and its environment, we abstracted variables relevant to this problem from a master data set of Maya groups containing 53 cultural variables describing the economy, political system, agricultural practices, architecture, and ritual practices of each case. We used 197 variables to record environmental characteristics

quantitatively and qualitatively. All the environmental variables, as well as a number of the cultural variables, were borrowed from Dr. Lewis Binford's data set of hunter-gatherer groups from around the world. Additional variables relevant to agriculturalists, and specifically to the modern Maya, were appended by Shaw.

We removed a set of environmental variables from the Binford master data set for our analysis and selected variables for inclusion based on their presumed relevance to our hypotheses (see the environmental variables in appendix 10.1). We took these variables from more simple climatic measures, such as average monthly rainfall and temperature, soil type, and elevational variation. Two of the original forty-three cases—Ichaiche and Santa Cruz (Gann 1918)—were excluded from our analysis because of insufficient environmental data.

Appendix 10.1 lists the ritual categories we included in the analyses. If rituals were not specifically mentioned by the authors we surveyed, we excluded those cases from certain analyses.

The Analyses

The junior author conducted the statistical analyses using SPSS version 6.0 and with the assistance of Dr. Harold Hietala. Descriptive techniques were used to explore variation within the data set (crosstabulations, boxplots, and scatterplots), correlations (Kendall's tau-b), cluster analysis (hierarchical, using Ward's method and k-means), and principal components. Our initial strategy was to divide the cases into groups based on their environmental characteristics using cluster analysis. Then we evaluated the distribution and range of variability within each cluster. We next used correlations to explore relationships between ritual and environmental data and to determine the validity of the groups. Finally, we used a principal components analysis to identify the number of factors determining most of the environmental variability within the data set.

Our cluster analyses, both hierarchical (Ward's) and k-means, initially used all environmental variables. These analyses clearly divided the Maya cases into three to four groups. Because many of the environmental variables were derivations of one another, however, we felt that this procedure might have been emphasizing certain aspects of the environment at the expense of others. Therefore we performed a second series of analyses using only the basic environmental measures of rainfall, temperature, and elevation. This generated two groups, highland and lowland; elevational ranges in highland areas were swamping out the effects of other climatic measures. A third and final cluster analysis produced much better results. Based on only those environmental measures (see appendix 10.1) we thought directly related to plant growth, we produced six distinct clusters. Membership in each cluster was identical in the heirarchical and k-means analyses. We used these clus-

ters throughout the remainder of the analyses, as we thought they best reflected the different zones of environmental conditions related to plant growth in the Maya area.

Our next analytical step was to use descriptive methods to get at the variability within and between clusters. Boxplots determined that each cluster was sufficiently different in terms of MEDSTAB, PGROW, and WATD to allow the clusters to be ranked ordinally. The variables SUCSTAB, WATRGROW, WILTGROW, WRET, and WSTORAGE (see appendix 10.1) were also distinct for most, but not all, clusters. Thus it seems that MEDSTAB, PGROW, and WATD were the primary characteristics differentiating groups in the cluster analyses, although the other variables certainly also played a part. These boxplots also revealed that cluster F, which contained cases from highland and lowland areas, exhibited the widest internal variability, while A, C, and D demonstrated the least (fig. 10.1).

The next descriptive step, crosstabulations, demonstrated several significant relationships that were then confirmed using correlations. Although the same results were produced by both types of analyses, both were necessary. While correlations point out any linear relationships, they cannot reveal the concave or convex relationships visible in crosstabulations. A ritual variable state that only occurred at both high and low ends of an environmental variable would be apparent in a crosstabulation but nonsignificant in a correlation. We did not see such concave or convex relationships in the data, however, because of the number of missing cases, low group membership, and/or truly nonsignificant relationships. The only correspondences we found in crosstabulations were those already clearly visible in Kendall's tau-b correlations. The tables were valuable in interpreting correlations, however, by revealing where significant relationships were based on only a few cases.

Several significant correlations appeared in both the crosstabulations

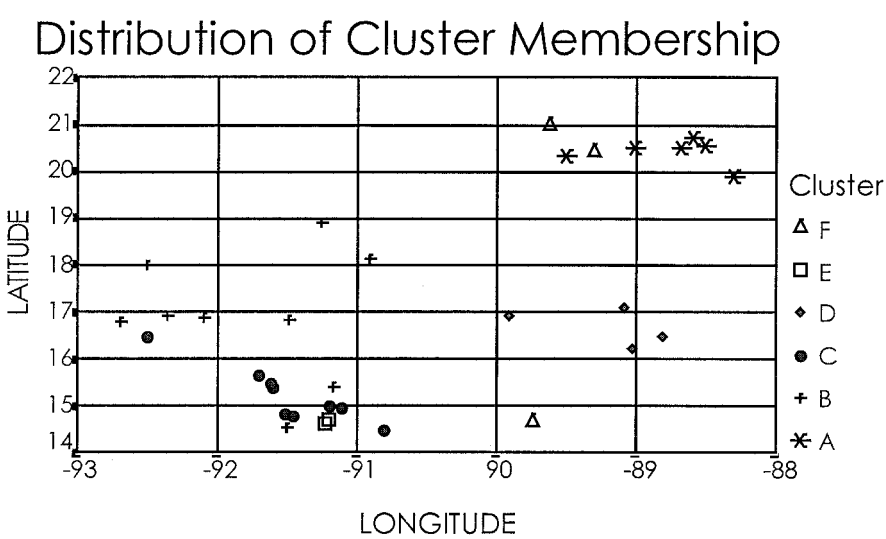

Figure 10.1. Distribution of cluster membership.

Table 10.1
Continuous Environmental Variables Versus Ritual Variables
(p-values < .05 in bold)

	MEDSTAB	*PGROW*	*RUNGROWC*	*WATD*	*WATRGROW*	*WRET*
AGMAIN	.505	.705	.261	**.040**	.147	.345
FRUITS	**.007**	**.011**	**.018**	**.025**	**.035**	**.009**

and correlations (table 10.1). We compared the continuous environmental variables we used in the final cluster analysis (MEDSTAB, PGROW, RUNGROWC, SUCSTAB, WATD, WATRGROW, WILTGROW, WRET, and WSTORAGE) to AGMAIN, AGPREP, ATONMENT, FRUITS, and RENEWAL. We removed MAINT from the analysis because of the number of missing cases and the lack of variability exhibited in MAINT among the cases.

We produced a second set of correlations using rankings of the clusters in terms of each of the growth-related environmental variables (table 10.2). These ordinal environmental variables were generated using the boxplots discussed earlier.

We think these two sets of correlations show that Maya ritual activity is linked with environmental conditions. According to the correlations with continuous environmental measures, Maya people practiced harvest rituals (FRUITS) on a greater scale in areas in which Mediterranean vegetation is less stable, potential growth is low, runoff is small, water deficit is high, and water retention is low. Thus Maya in high water deficit areas also tended to have larger agricultural maintenance rituals. The ordinal variables indicated that Maya had larger agricultural preparation rituals where potential growth was greater and Mediterranean vegetation more stable. Thus more energy was put into maintenance and harvest rituals where agriculture is more risky; in more stable areas, ritual energy is instead focused on the time of field preparation and planting.

The final analytical procedure performed was a principal components analysis. This analysis determined that three factors were responsible for 85 percent of the variation in the growth-related environmental variables (table 10.3). Although this analysis does not produce a tangible aspect of the environment for each factor, it can still provide insights into how environments, and thus rituals, vary. The first factor, with an eigenvalue of 5.13396, incorporates all variables except WILTGROW, WSTORAGE, and MEDSTAB. WILTGROW, and WSTORAGE load highly on the second factor (eigenvalue of 1.54988), while

Table 10.2
Growth-Related Environmental Variables Versus Ritual Variables
(p-values < .05 in bold)

	MEDSTAB	*PGROW*	*WRET*	*WATD*
AGPREP	**.009**	**.007**	.635	.495
FRUITS	.915	.915	**.043**	**.007**

Table 10.3
Variation in Growth-Related Variables (primary factor for each variable in bold)

	Factor 1	*Factor 2*	*Factor 3*
MEDSTAB	.36156	.04477	–.87391
PGROW	**.91356**	–.02535	.18733
RUNGROWC	**.94683**	–.08524	.21803
SUCSTAB	**–.70814**	.34452	.07871
WATD	**–.94389**	–.09478	.13861
WATRGROW	**.94170**	–.02326	.02981
WILTGROW	–.43014	**–.76357**	.15385
WRET	**.87886**	.12036	.21890
WSTORAGE	–.18855	**.90234**	.15549
Cumulative % explained	57	74.3	85

MEDSTAB is conditioned by a third (eigenvalue of 0.96841). Increasing the number of factors in the principal components analysis does not, and cannot, produce factors that are capable of explaining more of the environmental variation.

The Maya seem to have adjusted the scale of planting, crop maintenance, and harvest rituals to variable environmental conditions. Where agriculture was risky for them, primarily because of water availability, Maya farmers emphasized rituals concerning crop maintenance and harvest. In areas that appeared to be more stable, they gave precedence to rituals for planting and field preparation. Our analysis is by no means conclusive, but it does encourage us to explore the matter further. Unfortunately, the variables ATONMENT, MAINT, and RENEWAL did not pattern well with environmental variability. This was either because nonenvironmental factors conditioned these rituals or because the variables were too ambiguously defined. Since it seems unlikely that any part of a cultural system would be entirely unrelated to another part (the environment), the latter explanation seems to be most likely. Each of the three questionable variables characterized a wide range of ritual practices, unlike AGMAIN, AGPREP, and FRUITS, which were significantly correlated with many aspects of the environment.

Another potential problem in the analysis that may have prevented the production of more significant results was the way in which we calculated environmental risk. Because only monthly averages were available for the calculation of environmental variables, wide climatic fluctuations or cyclical catastrophic events were not apparent. Although several authors said that the groups they reported on were visited by such events with some regularity (Colby and Van Den Berghe 1969; McBryde 1945; Nash 1970; and Schwartz 1990), there was no way to include such anecdotal evidence in the data set. Consequently, exclusion of factors such as hurricanes, droughts, and plagues of locusts, just the sorts of problems noted in the Chilam Balam books, probably weakened correlations.

Despite this, the analysis provides some hard evidence for what many already take for granted: the presence, variety, and scale of Maya rituals reflect knowledge and social memory concerning their environments and climate. The Maya in this study were and are using rituals to anticipate and minimize risk by appeasing and thanking the supernatural forces thought to control crop production through a variety of means, climate among them. This knowledge has implications for both ethnographers of the modern Maya and archaeologists attempting to reconstruct the culture of the ancient Maya. With better environmental data and a refinement of ritual variables, it might be possible to formulate predictions about how Maya community ritualists would respond to a given set of environmental conditions. For our purposes, our preliminary patterns are a useful general analogy for extrapolation back to pre-Columbian Maya ritual behavior.

No doubt significant changes and developments accompanied such major transitions as the ninth-century collapse and the Spanish conquest. But our statistical analysis included examples from both ethnohistory and ethnography over the last five centuries. We believe that, like other basic features of Maya religion and ritual activity illustrated in *Maya Cosmos* (Freidel, Schele, and Parker, 1993), Maya ritual responses to more or less environmental risk have been enduring and relatively stable in expression. That is to say, within the context of an areal culture endowed with historical consciousness and even a precise means of chronicling during the height of lowland civilization, certain essential ideas and practices defined the parameters of possibility, structured expression, and gave credence to the continuities inherent to long-term tradition.

In the first part of this paper, we argued on a range of qualitative grounds that the Maya use ritual to conceptualize the relationships among people, crops, and environment. In the time of the Classic civilization, they used such rationales to legitimate hierarchical authority and the power of the kings. From what we can presently say about pre-Columbian Maya cosmology, the kings and their courts bridged our discovered dichotomy of ritual interests represented statistically in areas of relatively high and relatively low agricultural risk. To reiterate briefly, royalty recalled the sacrifice, dismemberment, and resurrection of a First Father who was both maize and the flesh of humanity. As Freidel, Schele, and Parker detailed thematically in *Maya Cosmos* (1993), the death and descent of First Father climaxed in the patterns of the Milky Way on 5 February, the beginning of field preparation in anticipation of planting (Thompson 1930). The thirteenth of August is the other axial day of the ritual year as seen in the patterns of the Milky Way. It is the day beginning this creation, and it is on this night that First Father is resurrected and reborn as a maize plant. It is also in the period of the most important maize cycle in much of the lowlands when rain is crucial to mature the tasseling plants after the "little dry season," or canicula. This day falls in the middle of the maintenance period and anticipates the harvest period in the agricultural cycle. We find this bridging of local ritual emphasis both significant and unsurprising. As many scholars have suggested, one

of the practical reasons for the successful regional integration of agrarian societies is the reduction of risk by means of a strategic redistribution of resources. Conceptually, Maya kings embodied both the risks and the successes of their farming constituencies. Practically, we think that they, their festivals, their tribute levies, and their gifts constituted the imperatives of evening out the risks of crop failure to avoid the chaotic effects of famine.

Maya Agrarian Economy as Political Economy

The hypothesis that Classic Maya governments had a central role in the overall agricultural survival of their constituencies is controversial, with some scholars suggesting that ancient Maya villagers prevailed despite their governments rather than because of their support. Nevertheless, it is a productive hypothesis. For example, the Petexbatun regional investigation recently completed by Arthur Demarest and Vanderbilt University clearly shows a precipitous decline and collapse of rural agrarian society in the wake of the collapse of political capitals there (see Demarest and Houston 1990). In this case, one might argue in Hobbesian fashion that the governments merely contained tendencies to intercommunity violence, for regional warfare is the main reason the governments collapsed. But of course a risk-reduction scenario is also predicated on discouraging intercommunity violence through the provision of food. The Petexbatun chaos might well have resulted as much from conflict induced by the collapse of an orderly redistribution network. Significantly, the final occupations in the region show evidence of attempts to fortify and defend agricultural areas.

In some cases, it is quite demonstrable that Classic Maya government encouraged agricultural development within urban zones. At Caracol in Belize, Arlen and Diane Chase have detected extensive terracing suitable for field cropping. They presently estimate that urban zone at greater than eighty square kilometers (around fifty square miles), virtually the entire area artificially modified by soil-trapping terracing (Chase and Chase 1996). William Folan and his colleagues have reported impressive reservoir and canal construction in the urban zone of Calakmul (1995), features that likely had agricultural as well as drinking-water functions. And we have known for some time that the landscape in the vicinity of the central peninsular site of Becan was significantly modified for agricultural purposes (Turner 1974). Matheny (1976) reports on the impressive water management systems at Edzna, a large center in Campeche with roots in the Pre-Classic. Hansen (1993) proposes that the impressive development of the El Mirador area of northwest Peten in the Pre-Classic period pertained to intensive agriculture based in terrace gardening that used peat deposits from the many *bajos* (swamps) near urban zones for fertilizer.

The role of Maya government in agricultural production must be considered in the context of several other major factors, particularly population increase and climatic variability, which must be accounted for when

interpreting intensification strategies and timing (Culbert and Rice 1990; Rice 1993; Gunn, Folan, and Robichaux 1995). The intellectual consensus in Maya studies continues to favor complex multiple-factor models for social development in the region. Even the recent report by David Hoddell and his colleagues (1995) of strong evidence for drought conditions during the time of the collapse of the southern Classic states (A.D. 800–1000) is being accepted cautiously as one more component in that phenomenon by long-term students of Maya cultural ecology. What such multicomponent models require, however, are hypotheses of agrarian economy as political economy that are commensurate with what we can now know about ancient Maya politics and social behavior.

A crucial feature of ancient Maya political economy, which remains largely ignored by students of the field, is currency (Freidel 1986; Freidel and Scarborough 1982). At the time of the Spanish conquest, the lowland Maya used a variety of commodities as broadly fungible currencies in their market transactions, most especially cacao, a lowland agricultural product (Millon 1955). These currencies, including lengths of cotton cloth, measures of salt, jade beads, red shell beads, copper bells, and axes, linked the economies of lowland and highland regions of Mesoamerica in trading arrangements that were mutually beneficial and controllable by governments through their traders. The Maya and other Mesoamerican peoples used the imperishable artifacts that served as contact-period currencies, with the notable exception of the metal objects, from Pre-Classic times onward. The notions that the Classic–Post-Classic transition in Maya country constitutes a major developmental cataract between peaceful theocracies and militant secular commercial empires must now be discarded in light of the evidence to the contrary for Classic warfare, to which we alluded earlier. Clearly, then, other kinds of correlative disjunction, as between Post-Classic currency-based economies and earlier Classic economies based in barter, must also be reviewed and perhaps discarded (Freidel 1986). Once one is prepared to consider Classic Maya economies, and even Pre-Classic economies, as heavily committed to the fungibility of strategic resources, then one can see that the risks and constraints of maize subsistence agriculture in the tropical lowlands may have given governments and elite hierarchies their major functional roles and legitimacy in the eyes of ordinary Maya.

We think that in the case of maize, fungibility is directly linked to storability. As Landa related in his description of life in Yucatan at the time of the conquest: "They had (others) made of certain red shells for money . . . and they carried it in purses of net . . . and at their markets they traded in everything there was in that country. They gave credit and lent and paid courteously and without usury. And the greatest number were cultivators and men who apply themselves to harvesting the maize and other grains, which they keep in fine underground places and granaries, so as to be able to sell (their crops) at the proper time" (quoted in Tozzer 1966:96, parenthetical interpolations in original). The fact that the lowland Maya sold maize for imper-

ishables such as red shell currency at the time of the conquest makes sense, for maize does not store for long periods in the lowlands. As the following review of current practices suggests, being able to store maize as money was a practical alternative to the risky and short-term possibilities of keeping surpluses of harvests in grain form.

Once cobs have filled out, maize needs to dry as quickly as possible in the field to permit its removal to storage facilities before birds, rodents, and other animals have the chance to cause significant losses. The harvest should not be rushed, however, as maize stored with a high moisture content is much more likely to be susceptible to insect infestation and the growth of fungi and bacteria (Bodnolt 1985). After the harvest, the emphasis remains on obtaining and maintaining a low moisture content. During storage, microorganisms and insects are the primary causes of grain loss, resulting in damage to anywhere from 5 to 50 percent of the stored crop. Insects tend to be more prevalent in corn stored on the cob, while bacteria and fungi thrive in any maize stockpiled with a high moisture content (Bodnolt 1985).

One would expect most Maya farmers to choose to store dry, shelled corn. As effort, available storage space, convenience, and other considerations also play roles in deciding how and where the Maya store maize, however, a variety of storage techniques are actually utilized. Maize is stored in three different forms, which correspond to different lengths of preservation: husked on the ear, shelled, and packed vertically on ears with maize leaves. Maize stored according to the first method is quite susceptible to vermin and generally should not be used for grain stored more than six months. Maize stored shelled will last a year if moisture content is sufficiently low. Packed ear maize, if arranged to minimize air pockets, provides the most ideal storage solution for the Maya in terms of preservation. Open cribs allow air circulation around the facility, but tight packing minimizes the space and oxygen available to rodents, insects, and bacteria attempting to infest the harvest. When properly carried out, maize may be banked for up to three years in such a manner. In all three types of storage, the addition of lime or calcium further helps to encourage drying and discourage pests.

At best, then, Maya farmers today can expect to store maize for three years. This is enough lead time to anticipate some fluctuations in production, but our own experience in Yaxuna in Yucatan during the nineties shows that droughts and hurricanes can prolong periods of failed harvests for many more years than that. The historical consciousness of climate fluctuation over the years, eloquently attested in the katun prophecies of drought and famine in the Yucatecan books of Chilam Balam, is commensurate with a rationale of support for governments and elites who took responsibility for maintaining the commerce that facilitated long-term storage of food through conversion into currency wealth. Likewise, such governments, through tribute and taxation, accumulated surplus wealth that could be converted back into food to feed their populations in the context of public works programs and corvée labor cycles. Such an integrated view of Maya political economy makes sense of the massive

projects these people undertook in both monumental construction and such agricultural projects as the terracing of landscapes around major communities.

Prophecy and Power: The Reckoning of the Maya Collapse

About a katun ago, Dennis Puleston (1979) wrote a remarkably bold and imaginative paper on Maya long-term historical consciousness. In that paper, Puleston suggested that the Post-Classic Yucatec Maya propensity to regard history as cyclical, manifest in the Chilam Balam books, might well be a legacy of the Classic period. He argued that a careful review of major Classic-period events at Tikal, as articulated by Clemency Coggins (1976) in a brilliant and prescient analysis, showed that the rulers there understood and responded to the Short Count cycle of thirteen katuns (256 years) as anchored in crucial episodes in their dynastic history. On that basis, Puleston proposed that the Classic Maya more generally may have regarded the ninth-century collapse as an amplified version of troubled times that occurred in the sixth century, as evidenced by the so-called hiatus, when portrait stones and stelae were not erected at some sites, that has been identified and discussed by many scholars of the Maya (Willey 1974).

Improved decipherment has proven Puleston and Coggins to have been wrong about the details, but the central pattern of attention to the Short Count cycle at Tikal is not only true but likely to have been impressive to the populace of that community in just the manner proposed by Puleston. Given that acknowledgement, we would like to build on his initiative by proposing that the Tikal Maya, and the elite of the of the Classic world generally, were indeed sensitive to the prophetic properties of the katun cycles and hopeful that they, the citizens of a given major capital, were in the hands of adepts capable of seeing them safely through the supernatural challenges of physical combat and sorcerous war.

The challenge is to find the metaphorical and mythological means to access the Classic-period rhetoric of war as it attaches to practical matters such as agricultural prosperity. One analogical lead relates to the way the Ancestral Hero Twins reveal themselves to their Middle World relatives, First Mother and Grandmother, when they are in the otherworld, as related in the Popol Vuh. In that narrative, the Twins plant a corn stalk in the center of their Middle World home and inform Mother and Grandmother that when they are alive the plant will prosper but when they are dead the plant will die. This direct tying of the cycle of the plant to the cycle of death and resurrection of the Hero Twins suggests that the combatants against the Lords of Xibalba were responsible quite directly for the prosperity of maize agriculturalists in general. The Lords of Xibalba in turn were portrayed as Death, Disease, and Affliction, but, in actuality, they were really the sources and causes of failure in maize fruition. Given this connection, one can see that the war gods of the Classic were actually those forces responsible for

causing crop failure and famine among enemies, with death and disease as known consequences, for the defendants of the realm were, like the Hero Twins, always focused on the essential goal of agricultural prosperity, of life itself, as portrayed in that metaphor and reality.

We can believe that there were important environmental perturbations in the course of Maya civilization. To think otherwise would be unrealistic in light of our present understanding of global climatological effects on this region. Whenever these perturbations actually occurred—and that is a matter for continuing investigation—we can pose the hypothesis that the response was ritually charged and related to the Maya conception of the basic human plan given in the creation story. On the one hand, those moments of dire straits, encapsulated in visions of death, spurred governments to prepare with stocks of food and wealth. On the other, periods of prosperity and good harvest would have encouraged arrogant visions of transcendence over death and destruction, as celebrated in the creation story, that authorized a depletion of those stocks in the name of grandiose public expressions of immediate power. In other words, in the last analysis, those in power wielded it to personal advantage most of the time, using the explanations available to them to further their own understandings and rationales. To return to Puleson's hypothesis, it seems quite likely to us that the Tikal Maya believed in the supernatural sanction of their return to power in the eighth century, after a cycle of descent into destruction and oblivion. It is also likely that other Maya were tracking the cycles of the katuns, celebrating them with confidence or bravado as the occasion permitted during the Late Classic period.

Nevertheless, Puleston's proposal that the collapse was a "full bore reenactment of the hiatus" (1979:69) fails in light of more informed perspectives on that phenomenon. The hiatus was not a regional reaction to the collapse of Teotihucan in Mexico or of any other outside force but rather Tikal's response to having been conquered by its enemies (Schele and Freidel 1990). If the Tikal Maya had a rejoinder to this catastrophe of the mid-sixth century, it was the celebration in the late seventh century of the return of the true kings in the form of Hasaw-Ka'an-K'awil, or Ruler A, off cycle but on target. From our perspective, then, the Maya did not fulfill some prophecy in the collapse; rather, the obligation of kings to ensure prosperity in the face of soil degradation in some areas, weather patterns that deprived crops of rain in others, population density in still others as proposed by Culbert (1993), and the mind-numbing realities of endemic war likely brought about a desperation in Late Classic warfare that required the extermination rather than submission of enemies. Such war, brought home in the end against those supreme governors who had wielded war for centuries as a matter of imperial ambition, resulted in the extermination of Tikal and the other major Classic centers of Maya civilization.

In our view, the Maya governments, beginning in the Pre-Classic era, understood their prime mandate to be agricultural ritual celebrations cementing alliances and facilitating the strategic redistribution of vital resources to offset the effects of local crop failure. The sensitivity of modern

Maya, through analogous ritual activity, to the variable success and failure of crops makes this a compelling hypothetical prospect. This rationale, metaphorically declared in the central role of maize in religion, underwrote a long and prosperous civilization. But as the Maya elite experienced long periods of agricultural prosperity, perhaps for centuries during the Classic period, they forgot this crucial function of their existence and allowed themselves and their institutions to be gulled into pursuing an array of priorities and ambitions that were no longer anchored in the necessities of sustaining their populations. So self-serving institutions (Flannery 1972) came into being not because of the iniquity or failure of character of individuals in power so much as because of the mind-dulling routines celebrating successes for which the elite could claim no reasonable credit, which were in fact the province of natural forces beyond their control or prediction. Maya historical consciousness was thus, in the last analysis, not so much a matter of acknowledging what happened in the past as a careful interpretation of the past that was amenable to the ambitions of the present. But if the Maya lords conveniently forgot specific past natural catastrophes as they pursued vendettas in war during the Classic period, their lore contained the truth in ways they likely reiterated in rituals regularly. The Quiche Popol Vuh (Tedlock 1985) contains many allusions to the cycle of maize relative to the success and failure of the human-form gods. Maya lords of the Classic period may well have equated feast and famine in food with their relative successes in struggling against the Lords of Xibalba, disease and affliction incarnate. In their minds, their political and economic rivals were simply the physical expressions of these ancient gods. To fall victim to them was to experience excruciating death beyond imagination; to prevail against them was to hope again that they could prosper with their people in the face of famine and chaos. So the nightmare of the collapse, of failure, lived on in the books of prophecy of Chilam Balam and in the story of the creation in the Quiche Popol Vuh. And beyond failure was survival and persistence, for in the end the Maya did defeat the Lords of Death to stand today, against the odds of modern conquest, war, and drought, to search out the ways to survive, just as the ancestral human gods learned to survive in their struggle against natural affliction. It is not the environment that ultimately challenges people but their own conception of the environment, and over the long term humanity must come to terms with this difficult reality.

APPENDIX 10.1.

Ritual Variables

Each of the following variables was ranked according to the following scale:

1. Such rituals are unknown in the society.
2. Such rituals are present but organized at the personal or family level.

3. Such rituals are present and organized at the community or camp level of participation.
4. Such rituals are present and organized at the multicommunity level of participation.

AGMAIN. This variable codes the scale and existence of agricultural rituals designed to maintain crop production. These were practiced in midseason (at the time of tasseling).

AGPREP. This variable codes the scale and existence of agriculture rituals designed to prepare crops, fields, and/or farmers for planting.

ATONMENT. This variable codes the presence and scale of rituals whose purpose was to supplicate the gods or plead for security.

FRUITS. This variable codes the presence and scale of "first fruits" rituals prompted by seasonal abundance for certain foods or resources.

MAINT. This variable codes the presence and scale of rituals whose purpose was to maintain a desirable state of being. These rituals were *not* focused on particular places or material symbols in real space.

RENEWAL. This variable codes the presence and scale of rituals whose purpose was to maintain a good relationship between man and nature. The rituals have finite spatial referents or material symbols.

Environmental Variables

Input data for the following environmental variables includes latitude, mean monthly temperature (in degrees Celsius), mean monthly rainfall (in millimeters), elevation (in feet), distance to coast (in kilometers), primary and secondary soil types, mean warmest month (in degrees Celsius), mean coldest month (in degrees Celsius), mean wettest month (in millimeters), mean driest month (in millimeters), and number of months between the mean warmest and wettest months. The environmental variables used in this analysis were then calculated according to Thornwaite and Mather (cited in Binford, Stone, and Johnson [n.d.].)

MEDSTAB. A successional stability measure that highlights growth associated with winter rainfall (such as Mediterranean vegetation, chaparral, schlerophyllous shrubs, etc.).

PGROW. A value from 0 to 36 that rates the potential for plant productivity.

RUNGROWC. The number of months in the growing season with runoff.

SUCSTAB. A measure of the probable successional stability of the plant community.

WATD. This measures water deficit in terms of the millimeters of water that would be needed to achieve the potential evapotranspiration (i.e., how much water was needed but not available).

WATRGROW. The number of months in the growing season with water retention in the soil.

WILTGROW. The number of months in the growing season at or below the wilting point.

WRET. This measures water retention in terms of the millimeters of water actually stored in the soil.

WSTORAGE. The potential millimeters of water stored by the soil.

Notes

1. Estimates of the lowland Maya territory vary. Sharer (in Morley, Brainerd, and Sharer 1983:19) used the New Mexico analogy and gives the figure of 324,000 square kilometers (125,000 square miles). Sabloff (1990:14) suggests 390,000 square kilometers (150,579 square miles). Schele and Freidel (1990:17) give 100,000 square miles.

2. See Michael Coe's *Breaking the Maya Code* (1992) for the story of the decipherment.

3. See Flannery and Marcus 1976; see also Flannery 1972 and Rappaport 1971 for the initial theoretical statements. In subsequent work, Flannery and Marcus (1983).

4. See Martin and Grube 1995.

5. See Freidel, Schele, and Parker 1993 for a review of the shamanic kingship in Maya civilization.

6. See introduction to Roys 1965. The fourth known Maya codex, the Grollier, was discovered after Roys and Thompson made their observations.

7. Victoria Bricker (1989) made the case for the transliteration of passages from the Chilam Balam books from the glyphic by pointing out the presence of final vowel-consonants that reflected the syllabic notation of the glyphic. For example, King Pakal of Palenque spelled his name syllabically Pa-Ka-La, and the final *ah* was silent when read. The Chilam Balam books contain such final vowels.

8. Fray Diego de Landa (Tozzer 1966) described contact-period ceremonies presided over by the goddess Ix Chel in which sorcerers and curers had their books and magical instruments blessed.

9. Personified diseases and afflictions continue to occur among contemporary Maya societies, as documented, for example, by Hanks (1990:342–349)) in Oxcutzcab, Yucatan, although "bad winds'' became another important source of Maya disease after the eighteenth century.

10. There are also high gods: Hun Ahaw is a documented way of the Classic period. See Freidel, Schele, and Parker 1993:263.

11. See Dennis Tedlock's introduction to his English translation of the Popol Vuh (1985). See also Coe 1989 for his discussion of the Ancestral Hero Twins in Classic Maya art.

12. My spouse, Carolyn Sargent, rightly warns me that the field of medical anthropology has a robust and detailed literature on disease causation and its relationship to practitioners that I have yet to absorb. Thus, with the caveat that the discussion in this paper is highly speculative, I hope that it gestures in a direction not only bold but eventually productive. I offer it as an opening only.

13. The clearest example of this is Hanab Pakal's nine katuns of history in the Temple of the Inscriptions at Palenque. This is his funerary temple, and in the text he details the adorning of the three state gods (which had been thrown down by enemies just before his birth) and the history of his successful reestablishment of his realm in conjunction with powerful allies.

14. The major epigraphic work on this subject is being carried out by Simon Martin and Nikolai Grube. Linda Schele and I noted the outlines of this regional struggle in chapter 5 of *A Forest of Kings* (1990), but we did not understand the extent of the hierarchies involved or all the rankings. When we were working on *A Forest of Kings*, Linda had a key decipherment in hand—"by his wish"—that defined relationships of superordination, but she deferred to other epigraphers who read this glyph as "in the land of" and thus missed an opportunity to see the grand alliances.

15. The Aztecs conquered the states along the Gulf Coast as soon as they had the ability, aided by immigrants from their own territory who had sold themselves and their children into slavery during an earlier episode of famine in the Valley of Mexico.

16. Arthur Demarest and his colleagues in the Petexbatun region of the southern lowlands are dramatically documenting the collapse period as a time of unending and unstoppable warfare. See Demarest and Houston 1990.

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Chapter 11

Social Responses to Climate Change Among the Chumash Indians of South-Central California

John R. Johnson

The Chumash Indians of south-central California lived in a territory of high ecological diversity and natural productivity. Yet studies of the paleoenvironmental record in southern California and the Santa Barbara region in particular demonstrate that Chumash peoples sometimes experienced climatic perturbations that adversely affected their subsistence regimes (Kennett, Kennett, and Ingram 1997; Michaelsen, Haston, and Davis 1987; Stine 1994). A number of researchers have gathered archaeological and ethnohistoric data to elucidate Chumash cultural responses to climate change (Arnold 1991, 1992a, 1992b; Colten 1993, 1995; Erlandson 1993; Glassow 1996; Kennett and Conlee 1998; Lambert and Walker 1991; Larson, Johnson, and Michaelsen 1994; Raab and Larson 1997; Walker and Lambert 1989). These studies demonstrate that climate-induced stress led to significant cultural change, but debate still rages over which hypothesis best explains social developments. Dissatisfaction with certain aspects of this debate has led the author to propose an alternative hypothesis regarding the role of Chumash chiefs in a regional economy shaped by climatic uncertainty.

While there is general agreement that unfavorable, prolonged environmental episodes affected Chumash society, no consensus exists among regional archaeologists regarding the significance of particular climatic events, likely pathways to socioeconomic change, or resultant forms of social organization (Arnold 1997; Fischman 1996; Raab and Bradford 1997). One hypothesis emphasizes that subsistence stress was brought about by dramatic changes in sea temperature and led to elite control over economic activities (Arnold 1991, 1992a, 1993, 1995). An alternative hypothesis proposes drought-induced competition for resources and political circumscription as the impetus for development of hereditary leadership (Raab 1994; Raab and Larson 1997). Setting aside differing emphases placed on triggering climatic episodes and alternative mechanisms proposed for social

change, these two hypotheses concur that the outcome was a society in which hierarchical social relations emerged (Arnold 1992a; Raab 1996).

Archaeological and ethnohistorical evidence for hierarchical relations within and between Chumash groups could presuppose an economy based on centralized political control, but when viewed from a regional perspective, this appears not to have been the case. The regional Chumash economic system was heterarchical in organization (Crumley 1979; Ehrenreich, Crumley, and Levy 1995), meaning that economic specialization between politically independent households and villages produced goods that were exchanged throughout the region for mutual benefit. What makes the Chumash case intriguing is that it offers an opportunity to study how environmental and social instability promoted heterarchical economic organization and how the latter may serve as a basis for hierarchical sociopolitical relations. This new model of Late Period Chumash social evolution builds on the discoveries emerging from studies of the paleoenvironmental and archaeological evidence through a regional analysis of intercommunity socioeconomic relations based on ethnohistoric records.

Environmental Setting

The Santa Barbara Channel region represents a transition zone among major geological, oceanographic, and ecological provinces of California (fig. 11.1). Northern and southern California truly come together, enriching and diversifying the resource base available to the native peoples who resided here. Three major mountain ranges meet in the Santa Barbara back country. At Tejon Pass in Interior Chumash territory, the Tehachapi Mountains come to an end as a southern extension of the Sierra Nevadas. Here also is the southern terminus of the San Emigdio Mountains of the Coast Ranges. These are met by the Western Transverse Ranges, unusual because of their east-west orientation. The high mountain ridges of the Transverse Ranges extend into Chumash territory to form the Santa Monica Mountains, Santa Ynez Mountains, and Northern Channel Islands.

The crosswise position of the Western Transverse Ranges relative to other ranges in California created the east-west orientation of the Santa Barbara Channel between the mainland and offshore islands. The cold-water California Current from the north rounds Point Conception to meet warmer waters moving into the Santa Barbara Channel from the southeast. For this reason, Point Conception is recognized as a major ecological boundary for many marine organisms. Warm water fishes and invertebrates have their northernmost limit there, and species that favor cooler waters reach their southernmost extent in the same vicinity. The cool California Current interacts with winds that push surface waters offshore, creating an upwelling effect that brings nutrients from deeper in the water column. This results in a plankton bloom in the Santa Barbara Channel that supports many species of marine life.

The distributions of various marine organisms fluctuate seasonally within

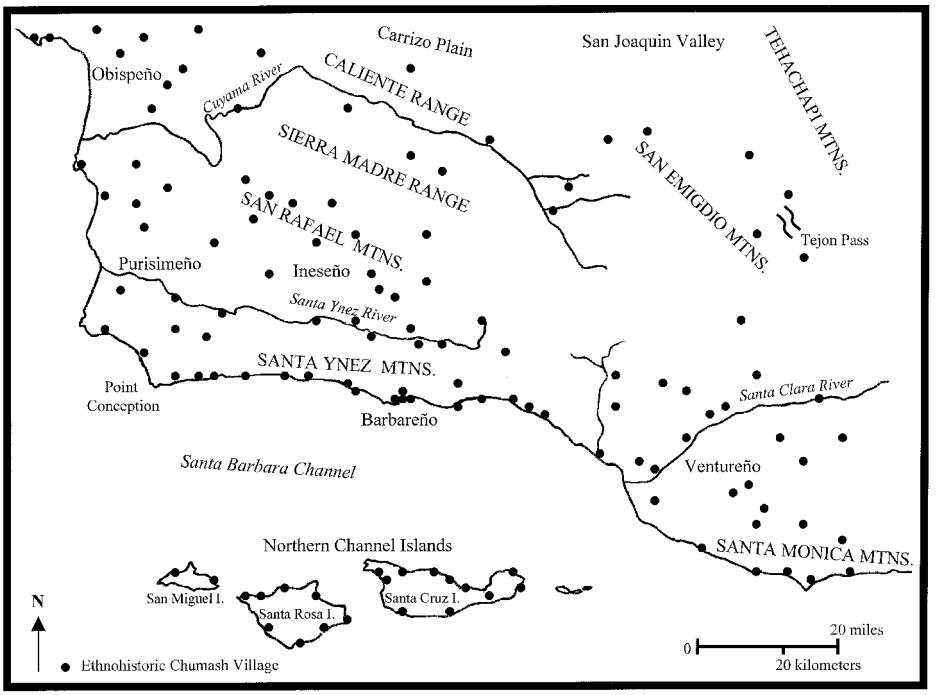

Figure 11.1. The Santa Barbara Channel region of south-central California, showing locations of Chumash settlements and linguistic groups.

the Santa Barbara Channel, depending upon water temperature. Periodically, El Niño–Southern Oscillations (ENSO) result in significant warm water periods that affect the mix and frequencies of various species in local waters (Casey, Weinheimer, and Nelson 1989; Glynn 1988; Radovich 1960; Tegner and Dayton 1987; see Dunbar, this volume, for the global context of the ENSO). As sea temperatures increase during warm water episodes, upwelling is suppressed and plankton populations decline, with concomitant disruption of the food web for fish, marine mammals, and sea birds (Roemmich and McGowan 1995). Warmer waters cause nearshore kelp beds to begin to die off, which in turn adversely affects a major fishery that was heavily exploited by the Chumash (Glassow and Wilcoxon 1988; Landberg 1975).

The Santa Barbara region is also the transition between major floristic and faunal provinces on the mainland. The coming together of mountain ranges, ocean currents, and vegetation communities created a situation where a number of zones of very different environmental characteristics were juxtaposed in relatively close proximity. The following description of a south-to-north transect of the central part of Chumash territory provides an example of these different communities (see Crumley, this volume, for a description of a comparable climatic hinge region in Europe).

Marine resources were the mainstay of people on the Channel Islands and along the mainland shore, yet considerable diversity existed in the types of marine ecosystems accessible to coastal Chumash communities. Rocky shore, sandy beach, estuarine, submarine canyon, and kelp bed habitats

were differentially distributed along the coast, and a temperature cline existed within the Santa Barbara Channel between warmer waters to the south and east and cooler waters to the north and west. As a result, various marine invertebrate and vertebrate species were locally abundant in restricted areas and seasons. In the foothills and valleys of the narrow coastal strip between the Santa Ynez Mountains and Pacific Ocean were coastal sagebrush scrub, grassland, and oak woodland communities that produced wild seed and acorn crops, small game, and deer. The Santa Ynez mountains were covered with chaparral with patches of oak forest and were located close enough to coastal settlements to be accessible for hunting-gathering excursions in appropriate seasons.

The Santa Ynez Valley is an extensive east-west–trending drainage on the north flank of the Santa Ynez Mountains that enters the sea north of Point Conception. Its much more extensive pine-oak woodlands and valley grasslands were heavily utilized for hunting and gathering by its Chumash inhabitants. On the north side of the valley are the rugged San Rafael Mountains, predominately covered with chaparral except for pine and fir forests on the highest peaks. North of the San Rafael Mountains is the Cuyama Valley, a dry region characterized by plant communities more typical of the Great Basin. Extensive areas of deciduous blue oak woodland, sagebrush scrub, and pinyon-juniper woodland were present in various parts of the Cuyama region. Some areas of tule, cottonwood, and carrizo marshes existed along the Cuyama River itself. Then came the chaparral-covered Caliente Range and the broad, alkaline flats and grasslands of the Carrizo Plain. The San Andreas Fault runs along the northern boundary of the Carrizo Plain. Beyond is the Temblor Range and then the broad Central Valley of California. Extensive tule swamps existed around large lakes in the southern San Joaquin Valley that were filled from stream runoff from the Sierra Nevada. This last territory had been settled by people speaking Yokuts languages by the time of contact.

Chumash Society at the Time of European Contact

By virtue of their diverse and relatively favorable environmental situation, Chumash population levels generally exceeded those found in hunter-gatherer communities elsewhere in North America (Keeley 1988). Permanent coastal settlements existed along the Santa Barbara Channel at the mouths of the largest coastal streams and estuaries (Landberg 1965). Coastal towns typically had several hundred people in residence, and the population of the largest of these exceeded one thousand (Brown 1967). Inland communities were generally smaller and spread more widely apart along major watercourses, but the largest of these also numbered several hundred inhabitants (Horne 1981; Tainter 1975). Settlements of the Channel Islands had a size distribution similar to those in the inland areas (Johnson 1988a). Both archaeological and ethnohistoric evidence document the surprising longevity of cer-

tain coastal towns over many centuries (Glassow 1992; Harrington 1928; King 1975, 1990; Kroeber 1925). The mixed subsistence strategy of terrestrial and marine resources to a certain extent buffered environmental variability and favored settlement permanence (Gifford 1926; Landberg 1965).

The presence of adjacent resource areas with high ecological diversity stimulated exchange among Chumash settlements. Spanish ethnohistoric accounts mention the Chumash acuity in trade (e.g., Sales 1956; Simpson 1961). A wide variety of food items, herbal medicines, pigments, manufactured goods, and raw materials used in the production of tools and ornaments moved among communities. Shell bead money, manufactured at a number of villages on the Channel Islands, were exported to the mainland and circulated as a medium of exchange among communities (Arnold and Munns 1994; King 1976). A ceremonial cycle that existed throughout the year offered periodic opportunities for social and economic interaction at intercommunity fiestas arranged by political leaders (Blackburn 1976; Hudson et al. 1977).

Chumash settlements seem to have been at times loosely organized into federations under the limited authority of paramount chiefs. Larger towns would sometimes have several chiefs in residence, while small villages had none. Extensive intermarriage took place among chiefly families, presumably as a means of strengthening political alliances. Chiefs were frequently polygamous, whereas most men were allowed only one wife. Chiefs and their lineal descendants tended to reside patrilocally (i.e., wives lived in their husbands' communities), while the opposite situation, matrilocality, prevailed among the general population (Johnson 1988a). Chiefs apparently derived some of their wealth and power from the opportunities provided by trade and by ownership of the sturdy watercraft used for fishing and crossing the channel between the mainland and islands (Arnold 1995; Johnson 1988a; King 1982; Martz 1992).

Warfare was endemic among the Chumash. Virtually every Spanish visitor commented on raiding and feuding between mainland communities.[1] Ethnohistoric sources record that the causes for intercommunity violence were competition for hunting, gathering, and fishing territories, failure to respond to invitations to fiestas, retribution for suspected witchcraft, and retaliation for attacks previously received (Johnson 1988a; Landberg 1965; Lambert 1994; King 1982). In a recent cross-cultural study, warfare frequency was shown to result from unpredictable natural disasters that destroy food supplies and spawn mistrust of others (Ember and Ember 1992). Ethnographic and ethnohistoric texts show that these causal factors appear to have been present among the Chumash.

Even though the bountiful marine environment and diverse ecology of the Santa Barbara Channel region favored population aggregation, the Chumash were nevertheless vulnerable to food shortages brought on by extreme environmental events (Larson, Johnson, and Michaelsen 1994). Ethnographic and ethnohistoric accounts document the existence of drought-caused stress that the Chumash attributed to the activities of evil shamans:

> Long ago, before there were white people here, a wizard . . . caused a great drought and famine that lasted for five years. . . . This sorcerer had a tablet or stone on which he painted many figures of men and women bleeding from the mouth and falling down. He took this out into the hills and exposed it to the sun, praying for sickness. For five years there was no rain, and many people died of hunger. The seeds the women had stored came to an end, and there were no acorns or islay.[2] Even the shells along the shore had only sand in them. When the men went out to get mescal only a few came back—the rest died of hunger. . . . Finally some other sorcerers spied the man who was causing all this and saw him going into the hills. . . . They followed the tracks and found the tablet or whatever it was with the evil figures on it, and they threw it into the water. Then the drought ended and it rained.
>
> (María Solares to John P. Harrington, quoted in Blackburn 1975:276)

Another source notes: "Scarcity of rain and of seeds proceed from certain men who among them are regarded as gods of the waters, and of the good or bad crops" (Fr. Estevan Tapis, 1803, quoted in Engelhardt 1932:8).

As these statements demonstrate, weather shamanism was well developed among the Chumash. Several types of special stones used in rainmaking are documented ethnographically and have commonly been recovered from archaeological contexts in central and southern California (Henshaw 1885; Hudson and Blackburn 1986; Yates 1889).

One pertinent Chumash myth linked climatic perturbations to the outcome of an annual celestial gambling game between Sun and Coyote of the Sky. If Coyote won, the year would be characterized by plentiful rain and abundant acorns, seed crops, and game, but if Sun were the victor, drought would ensue, and he would take his winnings in human lives (Blackburn 1975:37, 91–92). It has been argued that the two most important ceremonial gatherings during the year, the Fall Harvest Festival and Winter Solstice Ceremony, provided the contexts wherein Chumash shamans performed rituals to maintain cosmic balance and predict and/or influence the outcome of the celestial gambling game between Sun and Coyote of the Sky (Hudson et al. 1977; Hudson and Underhay 1978). Ceremonial commemorative events function to preserve significant social memories, in this case that climate is unpredictable and unforeseen impacts to food resources may arise (Connerton 1989; see papers by Crumley, Gunn, Hassan, and McIntosh in this volume for further discussion of social memory and past climatic events).

Paleoenvironmental Reconstructions and Archaeological Evidence for Cultural Change

Two major sources have been used to reconstruct Chumash environmental prehistory independent of archaeological evidence. Tree ring records allow the reconstruction of rainfall patterns (Michaelsen, Haston, and Davis 1987;

Stine 1994), and varved cores from the offshore Santa Barbara Basin allow the reconstruction of sea temperatures (Kennett and Ingram 1995; Kennett, Kennett, and Ingram 1997; Pisias 1978; Schimmelman, Lange, and Berger 1990). The recent accumulation of information regarding paleoclimate in the Santa Barbara region has allowed inferences to be made regarding certain periods in which Chumash culture would have experienced profound ecological stress. Generally speaking, extremely warm ocean conditions and multiyear droughts on the mainland had adverse consequences for native peoples dependent on fishing, hunting, and gathering (Arnold 1991; Glassow 1996; Larson, Johnson, and Michaelsen 1994). A decline in terrestrial productivity from drought does not necessarily imply, however, that sea temperatures were also warm (Botkin et al. 1991). Indeed the very strong El Niño event of 1997–1998 demonstrates that warmer waters often accompany increased rainfall, so in the past coastal peoples could turn to terrestrial food sources when marine resources were less abundant. The native islanders, who had a limited terrestrial environment accessible to them, were thus at greatest risk during ENSO episodes.

Most recent archaeological research and theoretical debate has centered on some severe, perhaps catastrophic, climate episodes that have been detected from about A.D. 900 to about A.D. 1300.[3] While the timing and severity of these events are still the subject of investigation, what is becoming increasingly clear is that Native American cultures throughout California emerged changed from what has been termed the Medieval Climatic Anomaly (Stine 1994). In archaeological terms, this time of change has been called the Middle-Late Period Transition (Arnold 1992a). Tree ring records show that two prolonged periods of diminished rainfall occurred in California as part of unusual climate changes that have been recognized through many parts of the world at this time (see, e.g., papers by Dean, McIntosh, and Togola in this volume). The first drought period was generally cool and lasted for more than two hundred years, from late in the ninth century A.D. to about A.D. 1100. The second, much warmer episode closely followed it after a very wet fifty-year interval and persisted until about A.D. 1300 (Scuderi 1993; Stine 1994).[4] These warmer terrestrial conditions in California did not apparently accompany comparable marine conditions. The most recent sea temperature reconstructions during the Medieval Climatic Anomaly indicate generally cooler waters during the entire period (Kennett, Kennett, and Ingram 1997; (Kennett and Conlee 1998). Cool sea temperatures imply increased marine productivity, but because the Kennetts' reconstructed curve is based on twenty-year sampling intervals, some short-duration warm water episodes cannot be ruled out.[5]

During the Middle Period preceding the Medieval Climatic Anomaly, a number of changes had occurred among the Chumash. Maritime fishing had intensified as a means of subsistence, with many technological innovations, including the advent of the plank canoe and proliferation of many types of fishing equipment (Davenport, Johnson, and Timbrook 1993; Glassow 1980,

1993; Hudson, Timbrook, and Rempe 1978; King 1990). Population generally increased, as measured by the number of radiocarbon-dated site components and simulated projections (Breschini, Haversat, and Erlandson 1992; Glassow 1996; Tainter 1972). The bow and arrow replaced the spearthrower as a hunting implement and weapon around A.D. 500 (Blitz 1988; Moratto 1984). Evidence that social ranking was present during this period has been found through the study of cemetery assemblages (Martz 1984, 1992). These developments set the stage for the impacts the Chumash were to experience from subsistence stress during the Middle-Late Period Transition.

Cultural responses to the Medieval Climatic Anomaly were notably different in parts of coastal central and southern California that were less densely populated than the Santa Barbara region. Along the central California coast north of the Chumash, the economy changed from one based on marine resources to a reliance primarily on terrestrial resources. Trade systems that had flourished during the Middle Period disappeared (Jones 1995; Jones and Waugh 1995). South of the Chumash, Takic groups, such as the Gabrielino and Juaneño, were organized into localized patrilineal clans in small settlements that appear to have had less permanence than those of the Chumash (Earle 1993; Jorgensen 1980; Koerper, Mason, and Peterson 1998). In a region of less ecological diversity, Takic peoples on the mainland may have reacted to environmental stress by locating settlements near perennial water resources and strengthening their local groups' territoriality (Koerper, Mason, and Peterson 1998; Raab and Larson 1997; True 1990).

The Chumash response to the Medieval Climatic Anomaly has become the focus of much current research and active debate. By the end of the Middle-Late Period Transition, community-level craft specialization and an elaborate bead money economy had arisen among the Chumash. Arnold has attributed these developments to the emergence of sociopolitical complexity stimulated by the need to buffer food shortages through trade (Arnold 1987, 1991, 1992a, 1992b, 1993). She argues that the heightened importance of craft production, specialization, and trade during this period fostered the rise of a managerial elite and social inequality. Arnold's model has been criticized by King (1990), who believes sociopolitical complexity arose much earlier; Jones and Hildebrandt (1995), who take issue with her so-called neo-Marxist approach; and Raab and colleagues (1995), who believe that the effects of elevated sea temperature may not have been as severe as supposed.

To determine other cultural effects of the Medieval Climatic Anomaly, research has been conducted on human skeletal remains from cemeteries dating to this period. The introduction of the bow and arrow, which appeared just prior to this time, coupled with competition for limited resources in a period of high environmental stress, seem to have resulted in high rates of mortality from violence (Lambert 1994; Lambert and Walker 1991; Walker and Lambert 1989). Skeletal samples from this period exhibit higher frequencies of indicators for poor nutrition and infectious disease (Lambert 1993; Walker and Lambert 1989). Population reconstructions indi-

cate an initial decline before the start of rapid growth (Glassow 1996). Following up on such studies, Raab (1996) argues that previous explanations for the rise of Chumash sociopolitical complexity have missed the mark. While admitting that environmental instability during the Medieval Climatic Anomaly contributed to sociopolitical change, Raab (1994) proposes that the main impetus for the strengthening of social hierarchies came from warfare and an increased sense of community territoriality that had arisen during competition for scarce resources.

How do we reconcile seemingly contradictory evidence explaining concurrent expansion in both economic exchange and intercommunity warfare during the Middle-Late Period Transition? The responses seem directly at odds with one another: one is centripetal, leading to circumscription and a more hierarchical society, while the other is centrifugal, fostering heterarchical intercommunity economic relations. Although warfare has been found to be a common response to unpredictable episodes of resource depletion (Ember and Ember 1992), for groups to have survived periods of subsistence stress, not all social interaction could have been belligerent. For example, positive social relations between coastal and inland areas would have been necessary to encourage the development of exchange relationships and facilitate the access of visiting groups to other communities' territories for the purpose of gathering specific resources. Among the Chumash, marriages between coastal and inland settlements served to cement such socioeconomic linkages (Johnson 1988a, 1990).

Coastal towns may well have granted territorial access to inland neighbors and relatives that allowed them to relocate at coastal fishing camps during summer months, the season of greatest scarcity in the interior (Glassow 1979; Spanne 1975; Tainter 1971, 1972). If during periods of drought and subsistence stress inland groups moved to the coast, then sites that yield archaeological evidence of limited, seasonal occupation would be expected along the shoreline. Seasonal fishing can be detected through archaeological indicators, for example, fish otolith growth rings or the predominance of certain fish species present only during the summer months (Landberg 1975). One archaeological site that may represent such a seasonal encampment used by inland groups is CA-SBA-1731. This site is situated in a coastal canyon between two permanently occupied coastal towns that had extensive kinship connections to inland towns during the early Historic Period. The periods of occupation at CA-SBA-1731 appear to correspond with the drought episodes of the Medieval Climatic Anomaly (Erlandson 1993). Seasonal indicators at this site reveal that maritime fishing took place only during summer months (Bowser 1993; Johnson 1983; Moss 1983).

The development of a heterarchical Chumash economic exchange system minimized the risk associated with unpredictable, unfavorable climatic episodes (Larson, Johnson, and Michaelsen 1994). The utility of such a system in this regard is demonstrated by its persistence beyond the period of prolonged environmental crisis that led to its inception and by the rapid

population growth that it appears to have encouraged. Spatial variability and high diversity in resource distributions within the region ensured that not all settlements would have been equally affected by droughts or severe El Niño episodes. Shell bead money continued to facilitate food exchange among communities to buffer the effects of local shortfalls (King 1976). Communities that had less resource variability within their territories appear to have been those that specialized in manufacturing items for export, for example, chert bladelet drills and beads produced by particular Island Chumash settlements, high-quality chert knives manufactured by the Purisimeño Chumash, and steatite cooking pots crafted by the Island Gabrielino (Arnold 1987; Arnold and Munns 1994; Glassow 1980, 1996; Wlodarski 1979).

Disruptions to the Chumash exchange system that occurred with the establishment of the Spanish mission system in the late eighteenth and early nineteenth centuries coincided with a period of climatic variability and warming sea temperatures. The migration of substantial numbers of Chumash Indians to the missions has been linked to resulting food shortages that the traditional exchange system could no longer buffer. In particular, an 1815–1816 El Niño event (the severest on record for the past three centuries) following a seven-year drought led to famine conditions for Chumash islanders, who suffered from depleted marine resources. The subsequent abandonment of most island settlements resulted from the absence of the traditional exchange system that would have alleviated subsistence stress. Migration to the missions, where more dependable food supplies were available, became the preferred option (Johnson 1988b; Larson, Johnson, and Michaelsen 1994).

Theoretical Considerations Regarding Chumash Social Change

What remains to be discussed is how the events of the Medieval Climatic Anomaly left their mark on Chumash social patterns. As discussed above, two competing models emphasize different pathways to the emergence of an elite group controlling intergroup relations. Arnold (1992a, 1993, 1995) proposes that ascribed leadership roles arose with a managerial elite that established hegemony over key resources and/or production and distribution processes. The alternative view emphasizes that a new elite became necessary to control warfare and violence through social means (Raab 1994). These competing explanations for why Chumash society changed during the Middle-Late Period Transition may partly result from a difference in *place* focus. Arnold's data are derived from intensive archaeological work on the Northern Channel Islands, while Raab bases his interpretation on investigations at Ventureño Chumash sites on the mainland. The responses to adverse climatic events may indeed have been different in these two subregions of

Chumash territory. Nevertheless, both theories concur that environmental stress led Chumash maritime hunter-gatherers to become socially complex and hierarchical in organization.

But how complex were the Chumash? How much control did their political leaders possess over intervillage economic and social relationships? Ethnohistoric accounts describe the existence of certain "big chiefs" who possessed some form of authority over neighboring communities, but chiefs in general had limited power (Johnson 1988a:291). Although it is known that chiefs were among those who owned the plank canoes that were of critical economic importance for fishing and use in crosschannel trade (Arnold 1995), they are not known to have been exclusive owners of such watercraft. Membership in the ethnographically described guild called the Brotherhood of the Canoe was not restricted to those of chiefly lineage, although the canoe's significance for the economic survival of the community probably conveyed considerable status on canoemen (Hudson, Timbrook, and Rempe 1978).

Although he has not embraced the theory that climate-induced stress produced a transformation of Chumash society, King (1981, 1990) has presented a third model of change during the Middle-Late Period Transition that yields useful insights. In his view, the great increase in the use of bead money during the Late Period resulted from a reduction in economic power held by Chumash political leaders and concomitant development of a secular exchange system in which individual entrepreneurs could participate. Indeed King's model would appear to find support from recent archaeological evidence from many Channel Island Late Period habitation sites where shell bead manufacture appears to be the result of independent household production (Arnold and Munns 1994). The community-level specialization that arose in many different parts of Chumash territory need not have resulted from elite control over household production but rather from entrepreneurial responses by local groups to increased demands for local resources and crafts that could be exchanged for critically needed nonlocal items. Chumash economic exchange may not have depended on the development of hierarchical organization but rather on regularized heterarchical relationships that took advantage of the natural environmental diversity of the region through the use of shell bead money.

Elements from various models proposed for Chumash social evolution fit together to form a composite picture of the consequences of climate-induced environmental stress during the Middle-Late Period Transition. Increased warfare resulted from unpredicted resource shortages. Increased production of standardized shell bead currency promoted the development of a heterarchical economic exchange system that buffered local fluctuations in food supplies over a large, diverse region. Setting aside for a moment the important issue of when and how elites arose, what further can be said about the social consequences of increased intervillage enmity and exchange among the Chumash? Answers to this question are suggested by analyses of detailed ethnohistoric data on marriage patterns and population distributions. Two features

of Chumash society in particular may be viewed anew in light of recent theories regarding cultural responses to the environmental instability of the Middle-Late Period Transition: (1) matrilocal postmarital residence and (2) the role of a community's relative position in the exchange networks. It is this author's view that hierarchical sociopolitical relations may develop as a consequence of heterarchical economic systems, such as those that arose among the Chumash.

Matrilocal Residence and Aggression

Counter to the expectations of previous researchers, quantitative studies of Chumash postmarital residence based on evidence from mission registers reveal a predominant pattern of matrilocality. Consideration of the movement of spouses between villages reveals that around 70 percent of the time women's mates came from other villages (Johnson 1988a). This discovery was previously unsuspected by ethnographers, because better-documented groups to the east and south of the Chumash possessed patrilocal clans and lineages (Gifford 1926; Harrington 1942; Kunkel 1962; Strong 1929).

Theories regarding the causes for matrilocality versus patrilocality have emphasized several possible factors, including the relative importance of women's contribution to subsistence, the degree of external warfare, and the timing of migration. The most recent statement on the subject is by Divale (1984), who developed and tested a theory of progressive changes in residence and descent. Using a worldwide, cross-cultural sample, Divale found no support for the hypothesis that residence preference correlated with the contribution of women to subsistence. Instead, he based his theory on a discovery in previous studies that matrilocality occurred in societies engaged in external war, while patrilocality correlated with internal war (Divale 1974; Ember 1975; Ember and Ember 1971; Otterbein 1968).

Where frequent feuding occurs among neighboring communities, there seems to be a general tendency for consanguineous male relatives to live close together for protection. External warfare, on the other hand, is incompatible with internal feuding within a group of communities, because a society torn by dissension would be unable to withstand an outside threat. Matrilocality prevents the creation of feuding residence groups of patrilineally related males and is therefore given a selective advantage under conditions of external aggression. Divale's theory predicts that matrilocality most often develops in societies where recent migration has resulted in strife between newcomers and those already inhabiting a region. This theory further suggests that matrilocal societies are characterized by institutions and facilities for socializing unrelated males, including men's houses where men gather for rest and relaxation (Divale 1984:20–26).

With some modification, Divale's theory provides useful insights for understanding Chumash residence patterns. Considering the recency of migration, both linguistic and archaeological evidence yield clues regarding

past population expansion in Chumash territory. Although grammatical and lexical comparisons of Chumashan languages indicate that the Northern branch (Obispeño) separated from the Island and Central branches as long ago as 3000 B.P., the divergence of languages within the Central branch has been estimated to have occurred about twelve hundred years ago based on lexicostatistical approximation, that is, just prior to the Middle-Late Period Transition (Klar 1977; Levy 1998). Rapid population growth, as reflected in frequencies of radiocarbon dates, appears to have begun around this time (Glassow 1996). The differentiation and spread of the Central Chumash languages (Barbareño, Ineseño, Purisimeño, and Ventureño) took place over the region from the coast to the border of the southern San Joaquin Valley and from the vicinity of the Santa Maria River south to the western fringe of the San Fernando Valley. Linguists have noted that a close relationship existed between coastal and inland dialects in the Central Chumash region. For example, the language originally spoken in the Castac–San Emigdio subregion was only dialectically differentiated from coastal Ventureño (Beeler and Klar 1977). Likewise, the language spoken in the Cuyama Valley appears to have been most closely related to coastal Barbareño (Harrington 1986).

The close similarity between coastal and interior Chumash dialects argues for population spread from the more densely settled coastal areas inland through fission and the creation of satellite communities. In a time of subsistence stress such as existed during the Middle-Late Period Transition, such an expansion would have resulted in increased external war and therefore favored matrilocality. It is interesting to note that the average estimated time depth associated with past migration for matrilocal-matrilineal societies is 1,003 years, very close to the beginning date of the Central Chumash spread indicated by lexicostatistics (Divale 1984:164–166; Levy 1998).

One difficulty with this scenario is that according to the definition used by Divale and others, the Chumash practiced internal warfare; that is, at the time of European contact, their intercommunity strife was between people who belonged to the same society and spoke essentially the same language (Divale 1984:117; Ember 1975:207; Otterbein 1968:277). The coexistence of internal war and matrilocality in Chumash society is inconsistent with the majority of cases included in cross-cultural studies. The existence of enmity between groups of allied villages, however, did provide conditions analogous to external warfare practiced in other societies. Matrilocal residence within a group of federated villages would have functioned to reduce strife within the group and strengthen intervillage alliances against other groups.

Another correlate of matrilocal residence is the presence of men's houses to socialize groups of unrelated males (Divale 1984). The Chumash possessed large ceremonial sweat lodges that functioned as men's houses. Harrington believed that these were equivalent in use to kivas found in Puebloan societies in the Southwest (Harrington 1922:126, 1942:9). A contemporary description of Chumash men's use of these earth-covered sweat lodges was provided by Pedro Fages in 1775: "The men do not often sleep

in their houses at night; but carrying with them their arms, bow, and quiver, they are accustomed to congregate in numbers in great subterranean caves where they pass the nights . . . [because] if they stayed home they might be surprised in their bed by the enemy whilst defenseless on account of the presence of their wives and children'' (Fages 1937:48). Fages's description not only supports the use of large ceremonial sweat lodges as men's houses but also indicates their function in uniting together groups of males for defensive purposes.

Network Centrality and Political Authority

Examining Chumash social behavior at the regional level reveals how their social organization was linked to an economic system that shared resources among settlements in different environmental zones. Geographic models of intercommunity social interaction assist in understanding the articulation between economic and political systems. Intervillage marriage patterns may be used as an index of how people from different communities interact socially, economically, and politically. By constructing Chumash kinship diagrams from mission register evidence, frequencies of exogamous marriages between villages have been tabulated.[6] Studies of Chumash marriage patterns on the mainland and islands through the application of social gravity model techniques and social network analyses reveal that clusters of intermarrying villages tended to crosscut environmental zones and that network centrality within these clusters correlated with Chumash towns where paramount chiefs resided (Johnson 1988a, 1990, 1993).

What factors operated to select a particular community as a capital for the paramount chief of a population that resided in a particular area? This question may be answered in terms of the geographic implications of the origin of an economic system that resulted in the distribution of resources throughout the Santa Barbara region and led to the evolution of Chumash chiefdoms. Various authors have differed as to the type of economic activity that was the crucial factor leading to the development of social complexity among the Chumash. Basically, two processes may be contrasted here: (1) economic redistribution and (2) trade between different resource zones, especially between the islands and mainland. Blackburn (1976) and Martz (1984) have mentioned the important role of redistribution in the rise of sociopolitical complexity among the Chumash. L. King (1982) and Arnold (1992a, 1993, 1995) have argued that control over island-mainland trade was a critical development in the emergence of ranked society among the Chumash. These two points of view echo a theoretical shift in anthropological theory regarding the role of redistribution in the evolution of chiefdoms. Earlier studies suggested that village specialization in resource procurement or product manufacture may have led to the emergence of chiefdoms to redistribute goods, while more recent research has emphasized politically exercised control over critical resources (Service 1962; Earle 1977, 1987, 1991; Raab 1996).

These two competing theories regarding the evolution of Chumash chiefdoms may be examined in terms of opposing geographical expectations. If redistribution were the key factor in maintaining the political authority of the paramount chief, then we would expect to find that the capital for a group of villages united under one chief would develop in the location most accessible to the population under his jurisdiction. The most effective political center in an economy based on redistribution would thus be the location that maximized efficiency in the flow of goods and services to the capital (Steponaitis 1978:426–428). If, however, trade were the critical variable in the equation leading to the rise of chieftainship, then villages located in positions where they could take advantage of trade between resource areas would become political capitals. To reiterate, redistribution as a basis for chieftainship emphasizes efficiency in the flow of goods to a center, while control over trade as a basis for chieftainship is based on the ability to broker exchange between villages in different resource areas. These two competing models make use of two distinctly different concepts of centrality in a social network: centrality based on *accessibility* (or *closeness*) versus centrality based on *betweenness* (Freeman 1979).

In order to evaluate the alternative expectations of these two models for explaining the development of Chumash political centers, I undertook two locational analyses of settlement patterns in the Santa Barbara region (Johnson 1988a:ch. 9). Both analyses used settlement locations, shortest path distances between each pair of settlements, and settlement populations in order to identify geographic centrality. The two analyses differed, however, on the type of centrality being measured: *accessibility* versus *betweenness*. The results of each approach were compared to information on villages known from ethnohistoric evidence to have been politically important centers.

The theoretical assumption that central places would develop in locations most accessible to the surrounding population in cases where redistribution of goods and services is the desirable outcome of an exchange network has never received a systematic cross-cultural test, primarily because extensive settlement pattern data are lacking in most ethnographies (Taylor 1975:57; Kasakoff and Adams 1977:48; Feinman and Neitzel 1984:65). At least two prior quantitative studies, however, demonstrated that geographic centrality predicted very well the locations of the villages that were most politically important to their regional societies (Kasakoff and Adams 1977; Steponaitis 1978).

The algorithm used to measure geographic accessibility within the Chumash settlement system was the vertex-substitution heuristic (Teitz and Bart 1968; Rushton 1979:117–128). A computer program, ALLOC (Rushton and Kohler 1973), was employed to perform this algorithm, using population and intervillage distance data from the Chumash area. This program predicted which towns would be most accessible to the population living in their surrounding areas when the region was successively subdivided into natural subregions based on geographic groupings.

The alternative model for the evolution of Chumash political complexity is that chiefs in coastal villages derived their authority by taking advantage of trade between the islands and the mainland to enhance their wealth, prestige, and authority. If this proposition has merit, then one would expect to find that the mainland coastal villages where the most powerful chiefs resided would be those that lay in between the greatest number of inland people and island people. Similar studies in Melanesia and Russia have suggested that betweenness appears to have been a factor in predicting political centrality (Hage and Harary 1981; Pitts 1979). To rank betweenness among Chumash coastal towns, an analysis was conducted to determine their geographic centrality in an exchange network that moved goods between villages on the Channel Islands and villages in the Santa Ynez Valley. Each inland-island pair was assigned a value derived from multiplying the percentage of island population represented by the island village with the percentage of inland population represented by the valley village. The betweenness index for each mainland coastal town was derived from summing the values of all island-inland connections that passed through that coastal town, based on shortest path distances.

The accessibility analysis, using the ALLOC program, predicted optimal centers that matched almost exactly the known distribution of the most politically important Chumash towns (fig. 11.2). The betweenness analysis augmented the accessibility information by suggesting a basis for hierarchical organization among political centers (fig. 11.3). Ethnohistoric sources indicate that the mainland coastal settlements of Dos Pueblos and Syuxtun were the two most important Chumash capitals within the study area. These two also held the largest betweenness ranking in terms of their geographic centrality between populations on the Channel Islands and populations in inland areas. This evidence leads to the conclusion that the chiefs of Dos Pueblos and Syuxtun derived their paramount authority over their neighbors by means of taking advantage of interregional trade (Johnson 1988a:ch. 9).

Further ethnohistoric data may be offered as support for this conclusion. According to Spanish sources, Yanonali, the paramount chief of Syuxtun, was the most powerful chief in the Santa Barbara vicinity (Bancroft 1886:377; Geiger 1965:14). Like a number of other Chumash chiefs, Yanonali was polygamous (Warren 1977). The plural marriages of Chumash chiefs may have derived in part from the need for political and economic alliances among villages. Yanonali was the only Chumash chief documented in the mission registers as having a wife from the Channel Islands. His marriage to a woman from Xaxas, the principal port of Santa Cruz Island, seems to underscore the chiefly role in interregional exchange.

The accessibility and betweenness analyses suggested that in fact both types of geographic centrality played roles in the selection of capitals for Chumash village federations. If our assumptions regarding the relationship between political geography and economy are correct, then both redistribution and intervillage trade were determining factors in the evolution of

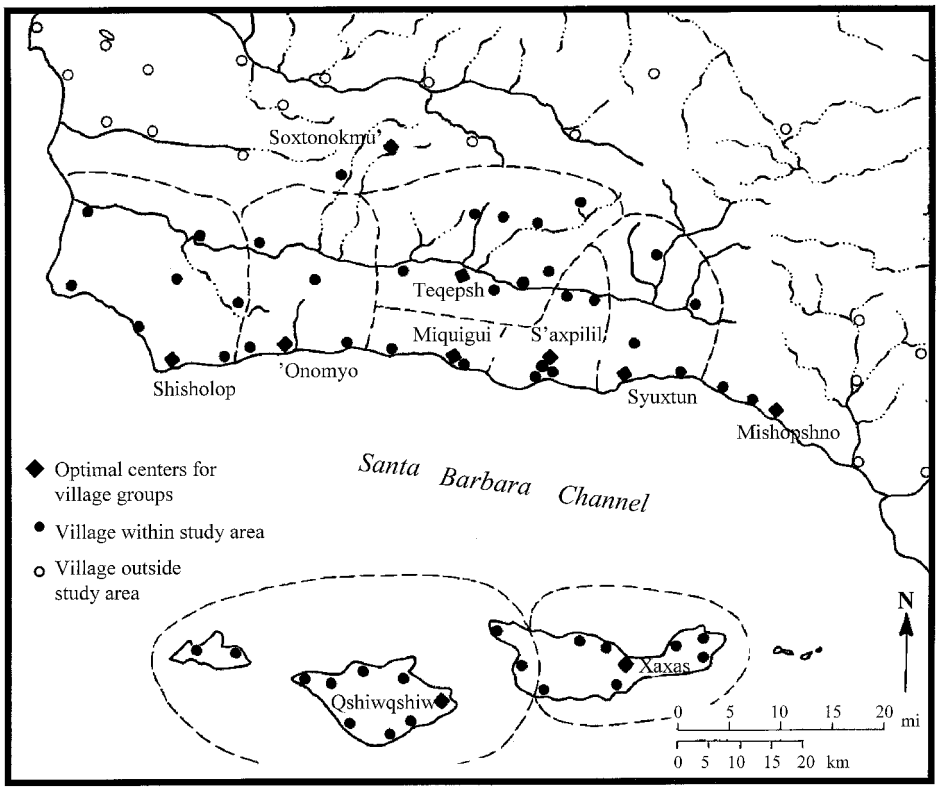

Figure 11.2. The most important Chumash towns documented in ethnohistoric records. (These closely correspond with optimal centers predicted by accessibility.)

chiefdom organization among the Chumash. The emergence of the Chumash economic exchange system in the Middle-Late Period Transition to buffer drought-caused food shortages, coupled with the need to defend home territories from transgression, provided some basis for strengthening political leadership, although when viewed from a regional perspective, the economic system remained heterarchical in nature.

Conclusion

Recent archaeological studies indicate that Chumash society changed dramatically during the Medieval Climatic Anomaly. Probably the most important development to buffer climate-induced subsistence stress was the creation of a heterarchical economic exchange system based on shell bead money that more effectively shared resources between different environmental zones. Warfare increased as communities defended home territories from which they derived their sustenance. Although violent conflict seems to have diminished after its peak in the Middle-Late Period Transition (Lambert

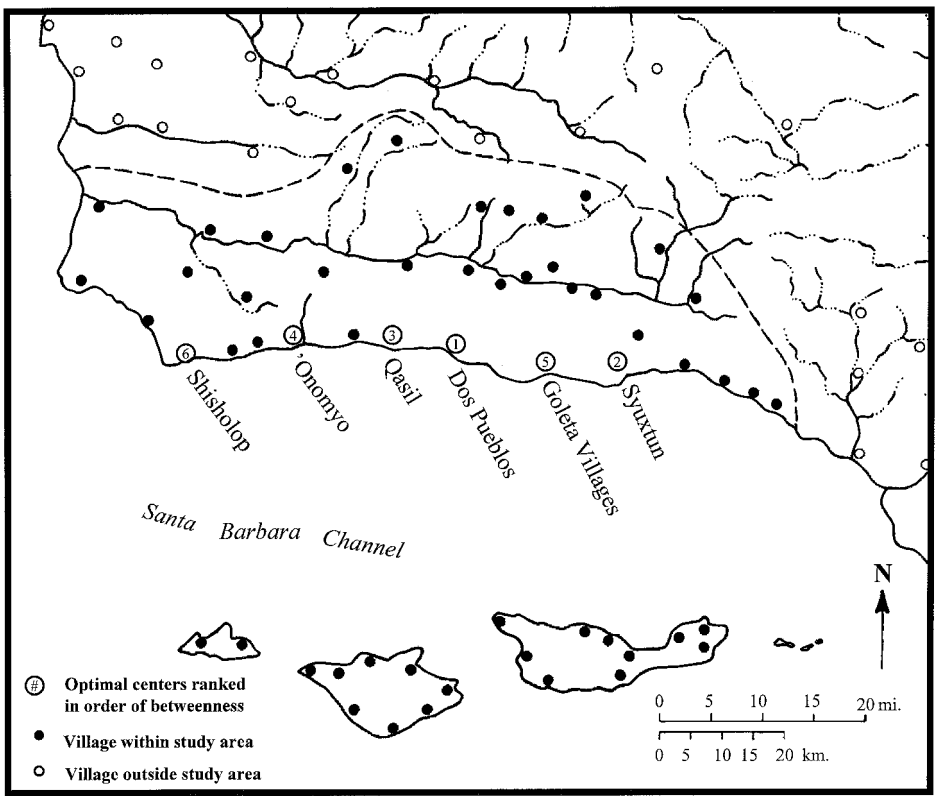

Figure 11.3. Mainland Chumash towns positioned as optimal centers within the regional exchange network.

1994), it was still a prominent feature of Chumash society at the time of European contact. Once the environmental crisis was resolved through a lessening of extreme conditions and increased trade, population expansion into inland areas may have changed warfare patterns from conflict internal to a group of communities to conflict between groups of allied communities.

Scenarios of climate-induced Chumash cultural change during the Middle-Late Period Transition have emphasized the rise of social hierarchies as a response to the need for resource management (Arnold 1992a) or defensive purposes (Raab 1994). While such factors may have been involved in Chumash social evolution, a more complete picture emerges when the focus of investigation shifts to the regional level. Analyses of ethnohistoric data from a sizable sample of villages located in different resource zones provide significant clues regarding how Chumash residence patterns and population distribution articulated with other processes of cultural change.

The ethnohistorically observed prominence of certain political leaders in mainland coastal towns accords well with expectations based on network models of predicted importance. Such models appear to be particularly well suited for analyzing regions in which heterarchical socioeconomic systems exist. Some chiefs were also in a position to take advantage of opportunities

to increase their wealth and political influence by virtue of their communities' centrality within this regional economic system. Chiefs in certain larger, mainland coastal settlements enhanced their standing by playing host to intervillage fiestas where alliances would be built, their wealth and status affirmed, and economic redistribution fostered. In this way, the heterarchical economic system that arose to meet the need for shared resources within an environmentally diverse region also contained the seeds of hierarchical differentiation. It is no surprise therefore that analyses of geographic centrality accurately predict those settlements where the most powerful chiefs are known to have resided.

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Notes

1. There may have been less violence among settlements on the Northern Channel Islands, which because of geographic circumscription may have evolved cultural mechanisms to reduce violence to promote community safety. Walker (1989) has argued that disputes among islanders may have been handled through nonlethal contests between aggrieved parties.

2. The boiled and processed pits of islay, or holly leaf cherry (*Prunus ilicifolia*), were a favorite staple in the Chumash diet (Timbrook 1984, 1984, 1990).

3. The dates given here have been slightly revised from those published by Stine (1994), based on his symposium comments at the annual meeting of the Society for California Archaeology held in Eureka, California, on 7 April 1995. During medieval times, there were big swings in the production of C-14 in the upper atmosphere, making calibration of radiocarbon dates tricky.

4. See n. 3.

5. An earlier marine paleoclimatic reconstruction by Pisias (1978) was the basis for Arnold's suggestion that a century-long period of elevated sea surface temperatures began around A.D. 1150 and created a crisis for marine-dependent Chumash peoples (Arnold 1991:956). This event has not been detected in more precise studies currently under way that use direct isotopic measurements of certain species of Foraminifera found in Santa Barbara Basin core samples (Kennett, Kennett, and Ingram 1997; Kennett and Conlee 1998). The author's own excavation at Shuku (CA-VEN-62A), a

Chumash coastal town that was occupied from the first century B.C. until the mission period, has produced indirect evidence of an event of unknown duration of pronounced sea temperature warming. A warm water clam species, *Donax gouldii*, occurs in great abundance in a specific midden stratum (separately dated in each of two excavation units) that, based on radiocarbon dating, falls between cal. A.D. 865 and A.D. 1200 (calibrated at 2 sigma, $p = .95$). Each sample produced an identical intercept of cal. A.D. 1025 on the radiocarbon age and calibrated calendar timescale curve (Beta-94463 and Beta-94464; marine shell; 13C/12C = 1.6; radiocarbon age adjusted for local reservoir correction = 1390 +/- 80 B.P.).

6. Only those unions formed prior to couples' arrival at the missions are used in this analysis of the native Chumash marriage network (Johnson 1988a, 1988b).

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Part 4

History and Contemporary Affairs

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Chapter 12

Global Change, History, and Sustainability

Joseph A. Tainter

Long before the advent of gender-neutral terminology, the great English poet Alexander Pope averred that "The proper study of mankind is man."[1] Yet in policy making today the human sciences are typically relegated to a secondary role, and the biophysical sciences have carried the day. The historical sciences in particular are routinely given little consideration in the making of contemporary decisions. The origins of today's problems are usually considered to lie no more than a few years in the past (Watt 1992). Our approaches to education and our expectation of continual technological innovation have made us averse to history (Tainter 1995; Lee and Tainter 1996). This aversion is inimical to sustainability. In the area of global changes in climate and other environmental factors we face challenges of a kind that previous people have confronted (Crumley 1994; Gunn 1994). One might expect, then, that in a rational, problem-solving society, archaeology and history would be at the forefront of public discussion. Of course they are not, and this fact condemns us to reinvent the wheel in the face of what may be humanity's greatest environmental crisis.

One purpose of the historical sciences can be to make the record of past human adaptations part of the international public discussion of contemporary climate change. Historical research should be considered in policy decisions as routinely as are the findings of climatologists and biologists. As responsible scholars who know the value of what policy makers ignore, we cannot complacently accept less. This paper proposes one approach by which historical analysis can clarify contemporary attempts to resolve environmental problems.

Approaches to Understanding Climate and Cultural Change

While it is easy to assert the potential value of historical research, it is somewhat more difficult to identify specific studies on which contemporary

understandings might be based. The assumptions, analyses, and conclusions of much research on past climatic influences will not bear careful scrutiny. In this regard it is worth discussing some archaeological and historical studies that relate climate and other environmental variables to cultural process and historical events. The lessons of this scrutiny will lead to a better understanding of what makes societies sustainable or not in the face of extreme environmental change.

The most extreme response a society can make to any challenge is to collapse. Collapse is a major, rapid loss (within two or three generations) of an established level of social, political, and economic complexity.[2] Collapse is a recurrent phenomenon, and one of history's greatest dilemmas. James Paton Isaac once wrote: "It goes without saying that the collapse of ancient civilization is the most outstanding event in its history" (1971:xi). Collapse perpetually attracts attention. Norman Yoffee has described the earliest-known written discussions of collapse, which appear in Mesopotamian historiography (1988:61–63). The topic has scarcely known an idle period since; it is a continual source of fascination and speculation. Today much of this interest concerns the relationship of cultural complexity to environmental change (e.g., Hughes and Thirgood 1982; Kaplan 1994, 1996; Ludwig, Hilborn, and Walters 1993).

When a society's collapse coincides closely in time to a change in climate, for example, many scholars find it tempting to link the two causally. Thus one of the most common explanations of collapse is that it is caused by changes in climate or some other factor that affects the resources on which a society depends. Such explanations occur in the literature of the Roman Empire, Mesoamerica, the southwestern and midwestern United States, Egypt, Mycenaean Greece, and other cases (e.g., Huntington 1915, 1917; Winkless and Browning 1975; Hughes 1975; Butzer 1976, 1980, 1984; M. Weaver 1972; Reed 1944; Kelley 1952; Wenke 1981; Doyel 1981; Griffin 1960, 1961; O'Connor 1974; Bell 1971; Carpenter 1966). With such a large and diverse literature one would think that the relationship of climate to sustainability and collapse would be well established. In fact, the reasoning behind these studies often does not support their conclusions (Tainter 1988:50–51, 1996c:689).

In the southwestern United States researchers are perpetually, and understandably, intrigued by the role of climate in stimulating cultural change. In this arid region, prehistoric people practicing subsistence agriculture are thought to have been particularly vulnerable to such things as protracted droughts, shifts in the seasonality of rainfall, lower temperatures, overhunting of game, nutrient depletion, and increasing alkalinity of cultivated soils (Martin and Plog 1973:322–325; Martin, Quimby, and Collier 1947:147). Southwestern archaeologists often point to extended droughts to explain the collapse of the Chacoan system (ca. A.D. 1150–1200) (Powers, Gillespie, and Lekson 1983:345; Schelberg 1982:273), the abandonment of Mesa Verde and much of the four-corners area (ca. A.D. 1300), and the collapse of Hohokam society in southern Arizona (fifteenth century A.D.) (Doyel 1981; D. Weaver 1972).

The U.S. Southwest does present one of the clearest cases where climate change and cultural change seem to have been related. Unfortunately, not all studies that address this relationship have done so in a clear and consistent way. The Hohokam of the southern Arizona desert, for example, were an agricultural people famed for their mastery of irrigation. They dug hundreds of kilometers of canals in the Salt-Gila river basins. The complexity of their society increased through time, and by what are called the Sacaton (ca. A.D. 900–1100) and Soho (ca. 1100 to 1300) phases, they were mobilizing labor for public works not directly related to subsistence. These included earthen platform mounds and ball courts, both features that have parallels in the complex societies of Mesoamerica. The Hohokam were one of the two most complex societies to develop in the Southwest, the other being the Chacoan society of the San Juan Basin of northwestern New Mexico.

The Hohokam society, like most, experienced both increases and decreases in its complexity. Hohokam archaeologist David Doyel (1981) sees evidence for diminishing sociopolitical complexity—a collapse—at circa A.D. 1100, between the Sacaton and Soho phases. The area of Hohokam settlement contracted at this time, material culture lost its former degree of uniformity, there is less evidence of high-status burials and craft specialization, and fewer ball courts were built. The degree of cultural and sociopolitical integration seems overall to have declined.

Various authors have suggested that climatic deterioration at the Sacaton-to-Soho transition helped to precipitate this contraction (e.g., D. Weaver 1972), a point accepted by Doyel (1981:61). On the face of it, the claim seems plausible enough: subsistence agriculturalists living in the Sonoran desert would certainly have been affected profoundly by major changes in the availability of moisture. Later in the Hohokam sequence, though, between the Soho and Civano phases (ca. A.D. 1300–1450), the trend of cultural evolution changed. Social differentiation, centralization, and complexity began again to increase at many sites (Doyel 1981:65, 68). Confoundingly, though, this development too is ascribed to adverse climate, specifically less moisture (Doyel 1981:74). At this point, one must pause and ask: how can climatic deterioration lead to both increasing and decreasing complexity? One or both of these causal arguments must be incorrect, incomplete, or both.

Other studies, in quite different parts of the world, exhibit similar uncertainties of reasoning. In a recent, well-publicized study, a research team investigating the north Mesopotamian site of Tell Leilan, Syria, concluded that an abrupt change in climate about 2200 B.C. caused "imperial collapse, regional desertion, and large-scale population dislocation" (Weiss et al. 1993:996; see also Abate 1994). At both Tell Leilan and other sites in this area occupational hiatuses of three hundred years or more start at about this time. Regional surveys have failed to find any ceramic assemblages of this period.

The archaeological deposits at Tell Leilan indicate that following a deposition of volcanic glass (tephra), an abrupt arid phase caused desertification. Perhaps hundreds of thousands of both agricultural and pastoral peoples were affected as the Akkadian Empire fell, and populations of Hurrians,

Gutians, and Amorites were displaced into southern Mesopotamia. Weiss and his colleagues postulate that an otherwise undocumented Anatolian volcano could have been responsible for the initial deposit of tephra but did not trigger the change of climate. Rather, this may have been caused by a northward shift in the polar jet and a stronger subtropical jet. Whatever the causal mechanism, the change in climate, it is thought, may have had consequences beyond the north Mesopotamian collapse. It is suspiciously synchronous with other collapses in the Aegean, Egypt, the Levant, and the Indus Valley (Weiss et al. 1993:999–1003; Bell 1971).

Unfortunately, the intellectual edifice erected to explain the north Mesopotamian collapse is undermined by other parts of the account. This was not the first episode of drying represented in the Tell Leilan sequence. Earlier, at about 2600 to 2400 B.C. (the Tell Leilan IIId period), there are indications of increased seasonality of water discharge from the Tur Abdin mountains, a decrease in soil moisture, and an increase in evapotranspiration. The flow of the Euphrates River may have declined far into southern Mesopotamia. Based on the arguments advanced to explain collapse around 2200 B.C., one might expect that the response would be declines in settlement size and sociopolitical complexity. Just the opposite happened, however: a state-level society emerged, Tell Leilan grew sixfold, urban planning was initiated, and the economy was structured around central storage and redistribution. In other words, complexity increased. The investigators link these events causally: centralized urban administration emerged to maximize agricultural production in response to increased variation in rainfall (Weiss et al. 1993:996–998).

If this scenario is correct, why was the strategy of increased complexity and centralization that was successful around 2600 B.C. either unsuccessful or untried around 2200 B.C.? Finding no answer in the Tell Leilan literature, we are left with an argument no more satisfactory than that for the Hohokam: deterioration in climate can lead to diametrically opposite societal responses.

Climate has also been implicated in the collapse of the Mycenaean polities, around 1200–1050 B.C. Archaeological surveys have shown clearly that there was substantial depopulation at this time. By one count a few years ago, the number of Mycenaean settlements declined from 320 in the thirteenth century B.C. to 130 in the twelfth and 40 in the eleventh. The population decline overall may have been on the order of 75 to 90 percent (Snodgrass 1971:364, 367). Rhys Carpenter once suggested that all this, as well as other thirteenth century B.C. upheavals in the eastern Mediterranean, was triggered by a change in climate that caused famine, depopulation, and migration. What appears to be a Mycenaean collapse in the Peloponnese was thus actually an evacuation to other areas, including Attica, forced on the Mycenaeans by drought (Carpenter 1966; see also Bryson, Lamb, and Donley 1974:47–50).

Ten years after Carpenter's thesis was published, John Chadwick questioned its logic (1976:192). Attica itself is dry, having only about half the rain-

fall of the areas where most settlements were abandoned. If drought caused the Mycenaean collapse and depopulation, why then would already arid Attica have seemed an attractive place to go? Why would Attica not have experienced the same problems even more severely?

My final example concerns resource decline rather than climate. I include it for two reasons. First, it is very difficult to draw a conceptual line between climate change and other kinds of environmental transformations: both affect human societies by changing the availability of resources. Second, it is useful to evaluate the reasoning of the argument, as it has been useful to inquire into the reasoning behind the previous three studies. The example has illustrative value.

In a general study entitled *Ecology in Ancient Civilizations*, J. Donald Hughes (1975) argued that the Romans failed to adapt their society and economy harmoniously to the natural environment. Specifically, he argues that deforestation led to soil erosion, the most economically mined mineral deposits were exploited, lands were overgrazed, and agriculture declined. Decreases in the quality and quantity of resources were therefore a major factor in the collapse of the Roman Empire. In later writing, Hughes focused particularly on deforestation as a cause of collapse (Hughes and Thirgood 1982).

Hughes's arguments about deforestation are intriguing in the light of recent research. Studies of Greenland ice indicate that lead smelting in the ancient classical world introduced so much lead into the atmosphere that it circulated throughout the northern hemisphere. Indeed the lead levels of the first century B.C. were so high that they were not matched until the industrial revolution. After the first century B.C. lead levels declined, but they were high throughout the Greek and Roman periods (Hong et al. 1994).

Much of the lead smelting in classical times was to produce silver. Although quantities of jewelry and silverplate were produced, most of the silver was made into coins to fund the activities of ancient governments, particularly war. In times of crisis Roman mints put out enormous numbers of coins. In the period from A.D. 293–300, for example, Roman mints were producing an average of over 2.7 million coins per day and up to one billion coins per year (see, e.g., Harl 1996:152, 217; Duncan-Jones 1994; Tainter 1994a). It is probably no coincidence that the peak of atmospheric lead in the first century B.C. coincided with the peak production of Roman silver coins to finance the century's frequent civil wars (Crawford 1974).

The environmental consequences of the massive coin production of the ancient world, particularly by the Roman Empire, have never been properly assessed. Certainly, very great amounts of charcoal would have been needed on a continuous basis, for all stages of production. Hughes and Thirgood estimate that an ancient metallurgical center would have needed up to one million acres of coppice forest for sustained production (1982:197–198), and this is in addition to the wood required to make bricks for massive Roman construction projects (such as the walls of Rome, begun by Aurelian in A.D. 271). Perhaps Hughes has a point. There must have been at least localized deforestation near urban centers and Roman mints.

Yet even if deforestation was a problem, there are reasons to be suspicious of Hughes's arguments for its consequences. For one thing, a major episode of likely deforestation in the third century A.D. (to produce coins and make bricks for fortifications) came about as a response to crisis, not a prelude to it. Moreover, if deforestation can contribute to sociopolitical collapse, should not regrowth of forests stimulate recovery or allow a society to avoid collapse? Research is showing that there was regrowth of European forests in the early Middle Ages (Randsborg 1991:16), and in at least some places forests started to return before the end of the Western Roman Empire (Waateringe 1983), probably a result of declines in both population and cultivated lands during the later empire (Jones 1964, 1974). Another factor may have been a significant decline in low-value coin production in the fifth century A.D. (Harl 1996; Tainter 1994a). If the cutting of forests endangered the Roman Empire, why then was it not stabilized by their return? Just as the forests were regrowing, the Western Roman Empire entered its terminal phase of weakness, and Europe was plunged into the so-called Dark Ages. Moreover the Eastern Roman Empire, which did not have access to the forests of northwestern Europe, did not collapse when the Western Empire did. Suffice it to say that the relationship of resource depletion—deforestation in this case—to the collapse of the Roman Empire is not at all clear.

There are also considerations of a more general nature. In one of the most interesting works of economic history, Richard Wilkinson (1973) showed that in late and post-medieval England, deforestation actually stimulated economic development; that is, rather than leading to collapse, it was at least partly responsible for the industrial revolution. Major increases in population, in around 1300, 1600, and the late eighteenth century, led to intensification in agriculture and industry. As forests were cut to provide agricultural land and fuel for a growing population, England's heating, cooking, and manufacturing needs could no longer be met by burning wood. Coal came to be increasingly important, although it was adopted reluctantly: Coal was costlier to obtain than wood, and its sources were limited. It required new, costly distribution systems (canals and railroads). As coal gained importance in the economy, the most accessible deposits were depleted. Mines had to be sunk ever deeper, until groundwater came to be a problem. Ultimately, the steam engine was developed and used to pump water from mines. With the development of a coal-based economy, distribution systems, and the steam engine, several of the most important elements of the industrial revolution were in place. Industrialism, that great generator of economic well-being, resulted in part from steps taken to counteract the consequences of resource depletion, supposedly a generator of poverty and collapse. Here is a curious paradox indeed and a heavy counterweight to Hughes's argument.

It would seem that many students of history have invoked too easily the deus ex machina of climate change and resource depletion to account for cultural transformations. In allowing ourselves to be seduced by such a convenient explanatory factor, we have proposed explanations of cultural change in which climatic deterioration can cause great cities to grow and polities to

become complex and yet also cause these systems to collapse. We have suggested that populations fleeing drought go to places where it is even drier. We have proposed that the depletion of a fundamental resource, such as forests, can contribute to the fall of a powerful empire, when other research suggests that responding to such a problem can lead a society to produce great wealth.

These remarks are not meant to suggest that all studies of climate have employed inconsistent reasoning or that climate change is unrelated to cultural change. Many scientists, such as Jeffrey Dean (see, e.g., 1996 and this volume) and Roderick McIntosh (see, e.g., 1994 and this volume), have taken care to build reasoned arguments that truly illuminate how climate can influence such things as population, aggregation, dispersion, mobility, subsistence processes, technology, ethnicity, and organization. We need more of such work. Yet at a time when policy makers need to understand historical responses to climate change, one cannot escape the conclusion that much of our literature is not yet a basis on which confidently to suggest understandings of contemporary problems.

Climate and Historical Processes

The explanations of cultural change reviewed in the previous section are not necessarily incorrect. It may be that the changes in question were climatically induced. The most immediate flaw is that the explanations are incomplete. Key arguments linking climate change to cultural change have, in each case, been excluded. The authors do not tell us how they reached their conclusions or how changing climates can stimulate very different cultural responses. In the pursuit of a universal causal factor—climate—history and process have been left out. But it is in the history of a society, seen in the context of general processes, that we will understand why a society responds to climate stress in one period by growing in complexity and in another by collapsing.

If the interpretation of the Tell Leilan sequence is correct, then the fundamental question is, Why was this society able to adjust to a climatic perturbation early in its history but unable to do so later? This question in turn stimulates several queries of a general nature. Was Tell Leilan peculiar in its changing ability to respond to climate, or is this a more widespread phenomenon? Is this flexibility specific to adaptations to climate, or does it extend to other spheres of problem solving? And, most importantly, why should it be so? Unraveling these questions will lead to a better understanding of the potential contribution of historical research.

There is in fact an age-old literature suggesting that, over time, societies often become less effective at confronting challenges or solving problems. One famous example is the Roman Empire, which survived major military disasters during the Second Punic War (218–201 B.C.) and went on, within very few years, to dominate the Mediterranean Basin. Yet the later Roman Empire was seriously weakened by losses at the Battle of Hadrianople (A.D.

378) that were, relative to the size and power of the Roman state at these times, much less severe than the defeats by Hannibal (Tainter 1988:196, 1994a). Similarly, the disastrous Germanic invasions in the early fifth century A.D., which ultimately led to the end of the Western Empire, were actually smaller than those that Roman armies had defeated in the late third century (Dill 1899:299).

The members of wealthy, industrialized nations will find it difficult to accept the notion that societies can lose their problem-solving abilities. Yet to ancient and some medieval writers the idea was not only acceptable, it was a truism (Alcock 1993). Ancient writers assumed that states eventually fail, and they—like us—had good evidence that often they do. It is worthwhile to discuss some theories of why states fail, for the investigation will clarify why societies respond to climate in different ways at different times. Much of the discussion will focus on early authors, for their work has set out basic themes that reverberate in contemporary thinking.

Organic Growth

Ancient classical Mediterranean writers thought that societies mimic organisms by passing through a cycle of growth, maturity, senescence, and death. The proper focus of intellectual activity was to determine where one was in the historical cycle and then to deduce corollary effects in the natural and social worlds (Mazzarino 1966; Alcock 1993). The organic cycle determines everything. Ancient writers often linked developments in the natural and social worlds: as one declines, so does the other. Thus the third century Christian writer Cyprian asserted

> that the age is now senile . . . the World itself . . . testifies to its own decline by giving manifold concrete evidences of the process of decay. There is a diminution in the winter rains that give nourishment to the seeds in the earth, and in the summer heats that ripen the harvests. The springs have less freshness and the autumns less fecundity. The mountains, disembowelled and worn out, yield a lower output of marble; the mines, exhausted, furnish a smaller stock of the precious metals: the veins are impoverished, and they shrink daily. There is a decrease and deficiency of farmers in the field, of sailors on the sea, of soldiers in the barracks, of honesty in the marketplace, of justice in court, of concord in friendship, of skill in technique, of strictness in morals. . . . Anything that is near its end, and is verging towards its decline and fall is bound to dwindle. . . . This is the sentence that has been passed upon the World. . . . This loss of strength and loss of stature must end, at last, in annihilation.
>
> (quoted in Toynbee 1962:4:8)

In the second century B.C. the Greek historian Polybius used organic reasoning to explain why Rome defeated Carthage. "Every organism, every state and every activity," he wrote, "passes through a natural cycle, first of

growth, then of maturity and finally of decay'' (Polybius 1979:345). When they came into conflict, Rome was ascending this cycle, while Carthage was declining. Employing such reasoning, Polybius made one of history's most remarkable forecasts. He predicted the fall of the Roman Empire six centuries before it actually happened (Polybius 1979:310).

The organic analogy has continued into recent scholarship, as evidenced in the works of Nikolai Danilevsky (1995; original 1869) and Oswald Spengler (1962; original 1918, 1922).[3] Although not so common today, one encounters it occasionally in contemporary scholarship (e.g., Haussig 1971:13, 14) and often in popular thought.

Conflict and Mismanagement

In this very popular school of thought, societies collapse because of elite self-aggrandizement and mismanagement or because of conflict between social classes. The fourteenth-century Arab historian Ibn Khaldun provided one of the earliest and clearest accounts of how elite mismanagement diminishes a society's ability to solve its problems. The founder of a dynasty, he argued, establishes a fair and equitable regime. His descendants, though, come to live in ever more luxury and raise taxes to pay for it. As taxes become burdensome, productivity is stifled, and the polity is destroyed (Ibn Khaldun 1958; original 1377–1381). Ibn Khaldun's theory is similar to some explanations of the Chinese dynastic cycle, where good governance gives way to exploitation late in a dynasty's history (Fairbank, Reischauer, and Craig 1973:72–73; Lattimore 1940:351).

In the early eighteenth century Giambattista Vico postulated that class conflict causes societies to disintegrate: "Through obstinate factions and desperate civil wars, they shall turn their cities into forests and the forests into dens and lairs of men'' (Bergin and Fisch 1948:381). Later in the same century C. F. Volney asserted that in ancient states, as a result of greed and class conflict, "a holy indolence spread over the political world; the fields were deserted, empires depopulated, monuments neglected and deserts multiplied; ignorance, superstition and fanaticism combining their operations, overwhelmed the earth with devastation and ruin'' (1793:51).

The idea that elite mismanagement and class conflict cause societies to become less able to solve problems is probably as old as hierarchy itself. It is quite popular in contemporary scholarship (e.g., Eisenstadt 1963; Yoffee 1988; see discussions in Tainter 1988:64–73, 1996c:689).

Complexity and Inefficiency

In a well-known paper, Kent Flannery (1972) argued that as societies grow more complex, their parts become so interconnected that a problem in one section spreads everywhere. As subsystems become specialized and less autonomous, stability declines. Roy Rappaport has argued along similar

lines but goes even further. He believes that complexity itself may be maladaptive (1977:65).

David Phillips's argument is different, but it too posits a decline in problem-solving ability with time (1979). Phillips argues that early states tend to use resources for noncritical or low-return purposes, such as building monumental architecture. Such expenditures can be suspended in an emergency, allowing for rapid reallocation of resources. In time, though, social and political institutions emerge that use resources more fully. Phillips calls this use "efficient," which he defines as "high output or return per unit of investment" (140). As more and more resources are allocated to such things as political offices, there is a decrease in financial reserves and a loss of flexibility. At this point, "historical accident alone is enough to touch off major failures" (142). A crisis such as a rebellion (or a change in climate), which a newly dominant state would easily control, becomes an insurmountable problem for an "efficient" society that lacks reserves.

Assessment

Each of these approaches suggests or implies that societies do in time become less able to solve problems and tries to explain why. If they are true, this would mean that societies will decline in their ability to adjust to climate change. Yet by themselves these arguments do not convincingly prove their central proposition: that the longer a society exists, the less likely it is to survive further. Some brief comments on each approach will suffice to make this point.

Organic Growth. Although the organic growth metaphor is rarely employed today, it will probably never disappear entirely. Alfred Kroeber both used and defended it (1944, 1957, 1958). Its flaws of course are both that it is vitalistic and that it offers no causal mechanism for the pattern (Tainter 1988:84, 1996c:689–690). Vitalistic arguments posit that a mysterious, internal vital force generates the growth, behavior, and mortality of an organism, a notion shed in biology decades ago.

Conflict and Mismanagement. Although many social scientists find models that postulate conflict and mismanagement attractive, nevertheless such models do not in themselves explain why a society's ability to solve problems such as climate change might decline. There are at least two reasons why this is so.

First, conflict models are at base psychological explanations. Implicitly they assume that there is an inherent human tendency to self-aggrandizement that persists even when it is dysfunctional. The evaluation of conflict models must therefore depend on whether one is content to explain the rich variety of human history by an unproven psychological constant.

Second, mismanagement models postulate (again implicitly) that elites

port population as they would any vital resource. The cases where this has not happened, such as the later Roman Empire, the tenth to eleventh centuries of the Byzantine Empire, or the later phases of Chinese dynasties, are matters to be explained. Merely observing that elites often become exploitative and so reduce societal flexibility (and their own chances of survival) does not advance understanding very far. Why, we may well ask, would elites act in ways that lead to their collective destruction? Though the question can be posed, the literature on conflict and mismanagement is silent in reply.

Models of conflict and mismanagement, as currently formulated, do not then account for declining ability to respond to problems. Of the critics of this approach, Ashok Guha has stated most succinctly one of the problems with this view. Social conflict, Guha suggests, "is the price of the existence of society itself; and since man cannot survive without society, it is hardly something that can be described on balance as dysfunctional" (1981:11).

None of these remarks suggests that elite self-aggrandizement and mismanagement are unrelated to changing abilities to respond to stresses. The point is that the existing literature does not satisfactorily explain how or why this comes about.

Complexity and Inefficiency. Arguments grouped under this heading postulate that complexity and specialization themselves bring on inflexibility and declining abilities to respond to new situations. Elman Service encapsulated such views in his "Law of Evolutionary Potential" (1960; see also 1975). Yet it is difficult to accept any model that postulates that societies are inherently static or incapable of change or that they cannot respond to alterations in climate, loss of resources, or other challenges. Aside from the conceptual difficulty of accepting this proposition, it founders on empirical points. There are many examples of societies that showed remarkable abilities to reformulate themselves late in their histories. These include the reorganization of the Roman Empire following the crisis of the third century A.D. (Jones 1964, 1974; Tainter 1988, 1994a), population movements and societal reorganization in southwestern prehistory (e.g., Dean 1996), the Late Classic Mayan renaissance following what is called the Hiatus (ca. A.D. 550–600) (Willey 1982), various phases of the Chinese dynastic cycle (Lattimore 1940), and the Byzantine Empire after the seventh century A.D. (Treadgold 1995).

David Phillips's (1979) model of declining flexibility in complex societies is of a different nature and is more compelling. He postulates that states become unable to respond to new contingencies because they lack financial reserves. Over time such societies allocate their resources in inflexible ways, and when an emergency arises, there is no fiscal reserve on which to draw. Collapse is thus a matter of probability: some day there will be an insurmountable calamity.

The problem with Phillips's model is that, like all the others considered here, it is incomplete. The assumption that fiscal reserves decline with increasing complexity denies to complex societies any flexibility and to their

leaders any capacity for rational action. The model assumes that states levy resources only at constant rates and that taxation is never adjusted to current needs. The approach does not recognize the possibility that a state might increase taxes and/or intensify production to gain more resources, as many states have done. Phillips's model does a fine job of describing how societies become unable to respond to new problems but does not explain why.

Summary and Commentary

Nothing reviewed to this point has seemed quite satisfactory. The studies suggesting that climate change or resource depletion can cause collapse did not explain why this should be so in some cases when quite contrary reactions are apparent in others. To respond to this dilemma, I discussed an age-old idea: that many societies through time become less able to solve their problems. Yet none of the various arguments supporting this idea seems able to sustain the conclusions they are asked to bear.

Yet with the exception of the organic-growth analogy, none of these theories should be dismissed as wrong. The inhabitants of Tell Leilan, for example, may indeed have adapted well to desiccation early in their urban history and unsuccessfully later on. This could have been because of elite mismanagement, overtaxation, or declining financial resources. The problem is that the studies described did not develop explanatory arguments that link cause clearly to effect. Yet parts of them, such as Phillips's model, can profitably be built on to develop a more comprehensive framework suitable for understanding not only the distant past but also more recent history and today's dilemma of climate change.

Historical Trends in Problem Solving

To understand if, and why, societies become ineffective at solving problems would be a significant contribution of the historical sciences to understanding contemporary conditions. It would also clarify many incidents of the past that scholars have found puzzling.

A state's ability to solve problems and its overall stability depend greatly on its return on expenditures on complex social, political, and economic institutions, as Phillips has pointed out. There is great variation in the return on such expenditures, both between societies and within individual societies over time. These variations substantially influence whether a society is stable or collapses. A theory developed previously to explain collapses (Tainter 1988) can be expanded to account for changing effectiveness at problem solving and for how a society responds to rapid climate change.

The theory is based on the following arguments (which are developed more fully in Tainter 1988, 1992, 1995, 1996a]).

1. Complexity costs, and increased complexity always imposes higher costs per capita (White 1949, 1959; Tainter 1988, 1994b, 1995, 1996b). These costs may be calculated in solar or other kinds of energy, human labor, time, or money.
2. In the history of humanity, complexity has been a primary problem-solving response (Tainter 1988, 1992, 1994b, 1995, 1996a, 1996b). Human societies have often resolved stresses and challenges by becoming more complex. This is seen in such spheres as (a) foraging and agriculture (Boserup 1965; Clark and Haswell 1966; Asch, Ford, and Asch 1972; Wilkinson 1973; Cohen 1977; Minnis 1996; Nelson 1996); (b) technology (Wilkinson 1973; Nelson 1996); (c) competition, warfare, and arms races (Tainter 1992); (d) sociopolitical control and specialization (Olson 1982; Tainter 1988); and (e) research and development (Price 1963; Rescher 1978, 1980; Rostow 1980; Tainter 1988, 1995, 1996a). In each of these areas, complexity increases through greater differentiation, specialization, and integration.
3. Because societies continually confront new stresses and challenges, there is an unending need to develop new solutions in resource production, sociopolitical organization, warfare, and information processing. These new solutions commonly involve increasing complexity at higher costs. This is why human societies have had a seemingly intrinsic tendency to grow more complex.
4. As is commonly the case with economic activities, increased expenditures on socioeconomic complexity reach a point of diminishing returns (Tainter 1988). This comes from the obvious incentives to discover and employ simple, inexpensive solutions before more complex, expensive ones. Thus hunting and gathering have given way to increasingly intensive agriculture and to industrialized food production that consumes more energy than it produces. Minerals and energy production move consistently from easily accessible, inexpensively exploited reserves to ones that are costlier to find, extract, process, and distribute. Socioeconomic organization has evolved from egalitarian reciprocity, short-term leadership, and generalized roles to complex hierarchies with increasing specialization.

The graph in figure 12.1 is based on these arguments. As a society increases complexity in order to resolve its problems, it expands investment in such things as producing resources, processing information, administration, and defense. The benefit/cost curve for these investments may at first increase favorably, as the most simple, general, and inexpensive solutions are adopted first. Yet ultimately inexpensive solutions are exhausted, and as a society encounters new stresses its evolution proceeds in a more costly direction. Ultimately a growing society reaches a point such as B1,C1 on the curve, where continued investment in complexity yields higher returns, but

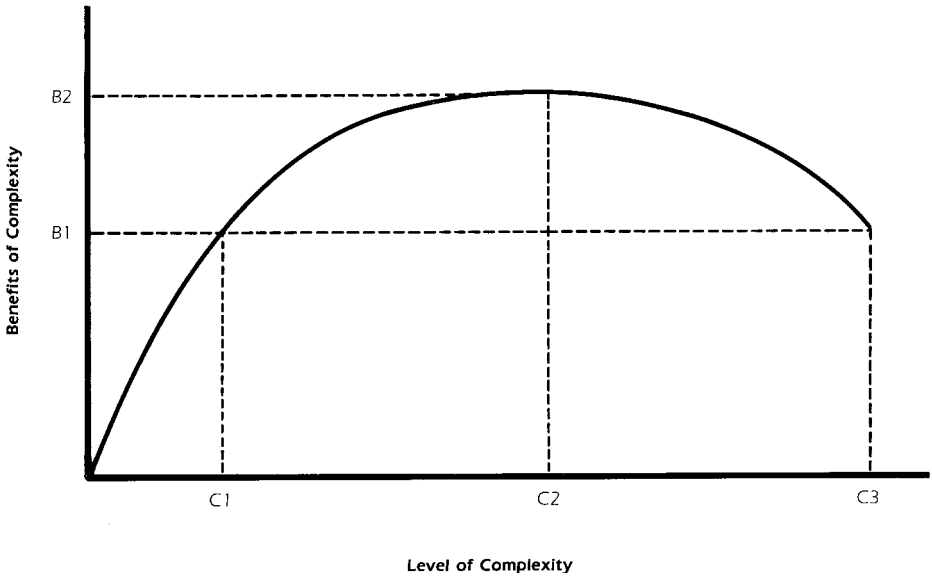

Figure 12.1. The marginal product of increasing complexity.

at a sharply declining marginal rate. When this point is reached, a society enters the phase where it starts to become vulnerable to collapse.

Two things make a society liable to collapse at this point. First, new emergencies impinge on a society that is investing in a strategy that yields less and less marginal return. As such a society becomes economically weakened, it has fewer reserves with which to counter major adversities. A crisis that the society might have survived in its earlier days now becomes insurmountable (cf. Phillips 1979, as discussed previously).

Second, diminishing returns make complexity a less attractive strategy; it is a condition that breeds disaffection. As tax rates rise and there are fewer benefits at the local level, more and more people are attracted by the idea of being independent. In technical terms, the society "decomposes" as people pursue their own immediate goals rather than the long-term goals of the hierarchy.

As a society evolves along the marginal return curve beyond B2,C2, it crosses a continuum of points, such as B1,C3, where costs are increasing but benefits have actually declined to equal those previously available at a lower level of complexity and investment. This is a realm of negative returns to investment in complexity. A society at such a point would find that, on collapsing, its marginal return on investment in complexity would noticeably rise. A society in this condition is likely to disintegrate rapidly.

The graph in figure 12.1 is not only a model of how societies become vulnerable to collapse, it also describes, more broadly, how problem-solving systems develop. In each sector of social investment—resource production, technology, competition, political organization, and research—increasing complexity is driven by a continual need to solve problems. As easier solu-

tions to problems are exhausted, problem solving moves inexorably to greater complexity, higher costs, and diminishing returns. Take the process far enough, such as beyond B2, C2, and the marginal cost of solving problems through increased complexity exceeds the marginal benefits.

Contemporary science, humanity's ultimate exercise in problem solving, illustrates this process. As more generalized knowledge is established early in the history of a discipline, usually at little overall cost, only more specialized work remains to be done. This tends to be more costly and difficult to resolve, so that increasing investments yield declining marginal returns. Some notable scholars have commented on this. Walter Rostow once argued that marginal productivity first rises and then declines in individual fields of research (1980:170–171). The great physicist Max Planck, in a statement that Nicholas Rescher calls "Planck's Principle of Increasing Effort," noted that "with every advance [in science] the difficulty of the task is increased" (Rescher 1980:80). As easier questions are resolved, science moves inevitably to more complex research areas and to larger, costlier organizations (93–94). Rescher suggests that "as science progresses within any of its specialized branches, there is a marked increase in the over-all resource-cost to realizing scientific findings of a given level [of] intrinsic significance" (1978:80). *Exponential* growth in the size and costliness of science becomes necessary just to maintain a *constant* rate of progress (Rescher 1980:92). Derek de Solla Price noted in 1963 that science was even then growing faster than either the population or the economy and that of all scientists who had ever lived, 80 to 90 percent were still alive at the time of his writing.

Scientists rarely think about the benefit/cost ratio to investment in their research. Yet if we assess the productivity of our investment in science by some measure such as the issuance of patents (fig. 12.2), the historical productivity of science appears to be declining. Patenting is a controversial indicator among those who study such matters (e.g., Machlup 1962:174–175; Schmookler 1966; Griliches 1984), but there is further evidence in a field of applied science where the return to investment can be determined more readily: medicine. Over the fifty-two-year period shown in figure 12.3, from 1930 to 1982, the productivity of the United States health care system for improving life expectancy declined by nearly 60 percent.

The declining productivity of the U.S. health care system illustrates clearly the historical development of a problem-solving field. Rescher points out: "Once all of the findings at a given state-of-the-art level of investigative technology have been realized, one must move to a more expensive level. . . . In natural science we are involved in a technological arms race: with every 'victory over nature' the difficulty of achieving the breakthroughs which lie ahead is increased" (1980:94, 97). The declining productivity of medicine is due to the fact that the inexpensive diseases and ailments were conquered first (the basic research that led to penicillin cost no more than $20,000), so that those remaining are more difficult and costly to resolve (Rescher 1978:85–6, 1980:52). And as each increasingly expensive disease is conquered,

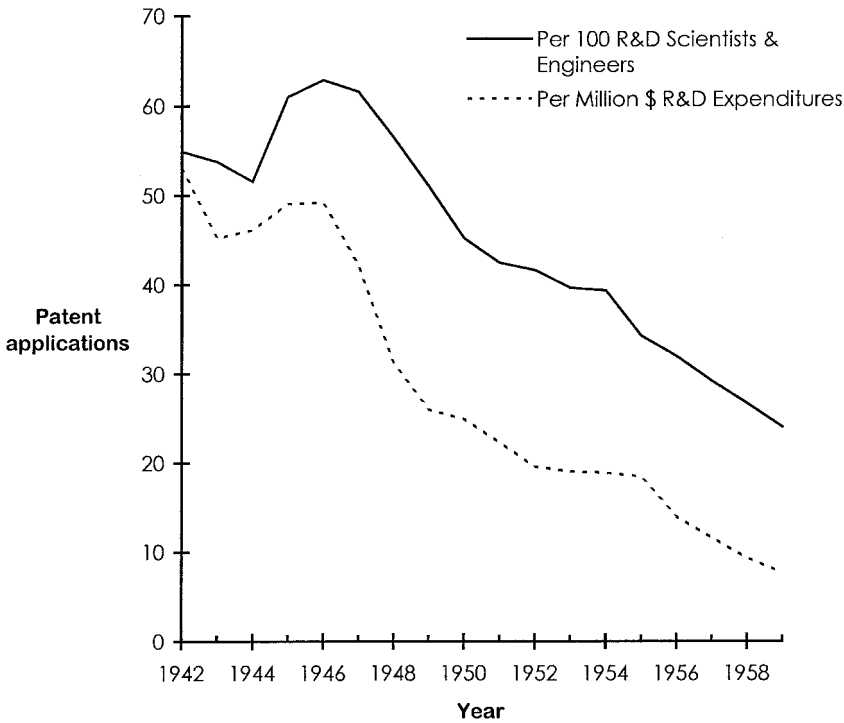

Figure 12.2. Patent applications with respect to research inputs, United States, 1942–1958.
Data from Machlup 1962:173.

the increment to average life expectancy becomes even smaller. The marginal return to medical investment progressively declines.

The case of medical research and application is important not only for its own obvious merits but also for what it suggests about the evolution of societal problem solving. Problem solving commonly evolves along a path of increasing complexity, higher costs, and declining marginal returns (Tainter 1988, 1995, 1996a). A system of problem solving that follows such a trajectory is not indefinitely sustainable. Ultimately fiscal weakness and popular disaffection cause such systems to be terminated or to collapse. Yet commonly when the solution to a problem is decided on, it is seen as a rational short-term measure. The higher complexity and higher cost of implementing the solution may appear only to be incremental and affordable. It is the cumulative and long-term effects, which typically are unforeseen, that do the damage.

While contemporary science is not strictly comparable to any previous institution in human history, its importance here is to illustrate the historical pattern by which problem solving develops. This trajectory of problem solving is a candidate for the linking arguments that seem to be missing in our literature. To the extent that it is a valid generalization, it accounts for the declining ability to solve problems that Phillips (1979) suggests characterizes established states and to which Polybius alluded in the second century B.C.

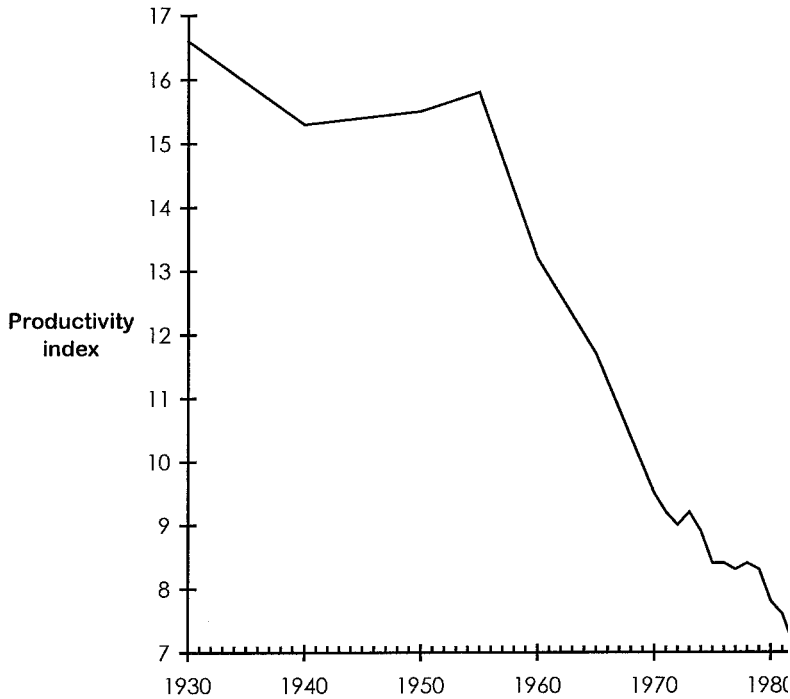

Figure 12.3. Productivity of the U.S. health care system, 1930–1982.
Productivity index = Life expectancy / National health expenditures as percent of GNP.
Data from Worthington (1975:5) and U.S. Bureau of the Census (1983:73, 102).

If diminishing returns to complexity render societies fiscally weak, and if problem-solving systems that evolve in this way are unsustainable, then differing responses to climate change may be understandable. If a society responds successfully to climate change early in its history, as did the occupants of Tell Leilan around 2600 to 2400 B.C., but continues thereafter to become more complex and costly, it may be less able to adjust to the next climatic perturbation. At Tell Leilan, from about 2400 to 2300 B.C., there was increasing investment in complexity. A defensive wall was built around the acropolis, storerooms and administrative buildings were constructed, and a system of numerical notation was employed. In the following century, 2300 to 2200 B.C., Tell Leilan was incorporated into the Akkadian Empire. Agriculture was intensified, water courses were channeled and cleared, a system was established to issue standard rations to workers, and for the first time a wall was built around the entire city (Weiss et al. 1993:998–999).

It is clear, then, that after the initial desiccation, the society at Tell Leilan increased its investment in complex institutions. Ultimately it was incorporated into an empire that institutionalized this process. We cannot be certain without more information whether these investments had reached the point of diminishing or even negative returns or whether they lessened the ability

to solve problems. Yet whenever a society undergoes a period of growing complexity and costliness and then suddenly fails to master a familiar problem, the cost of complexity may well be implicated. The evidence of increasing complexity at Tell Leilan suggests a focus for further research that is certain to strengthen our ability to explain the collapse in around 2200 B.C.

Similar processes were at work in the Chacoan collapse in the arid North American Southwest. A drought from A.D. 1134 to 1181 is sometimes blamed for the demise of the regional Chacoan system (Powers, Gillespie, and Lekson 1983:345; Schelberg 1982:273; Lekson 1996:130). Yet the Chacoans had survived previous droughts, and clearly knew how to find and manage water. The drought, however, coincided with a period when the Chacoan system had grown in size, complexity, and cost. There had been a florescence of construction, and many new communities had been added to the Chacoan network. While earlier communities had been established in the high-diversity terrain at the edges of the San Juan Basin, the later ones came to be founded in the less productive interior of the basin. When the drought began, the Chacoan system was experiencing increases in size and complexity and diminishing returns to complexity. Rather than directly cause the collapse, what the final drought did was to change the curve of marginal return on investment in complexity from a smoothly to a sharply declining one, and so it hastened the end (Tainter 1988:178–187).

Responding to Contemporary Environmental Change

This discussion suggests a new arena in which the historical sciences can contribute to our response to contemporary environmental change: study of the evolution of problem solving. No field of learning has taken this on as its particular focus. The history of science, for example, deals with matters of philosophy, discovery, intellectual traditions, and paradigm change. It could not possibly address the history of problem solving in societies that lacked formal science. Similarly, economic history tends to concern itself with matters of interest to economists, who dismiss as externalities much that other social scientists find important. Not only *can* the historical sciences fill this void, *only* we can do so.

It may be forcefully argued that sustainability is not possible unless we know where we are in history (Tainter 1995, 1996a). Economic patterns, such as the cost of complexity, may unfold over periods of generations or even centuries (Watt 1992), so that they are unrecognizable in the experience of a lifetime. It is impossible to evaluate our current economic position without knowing where we are in these historical processes. Is our investment in environmental research, for example, yielding increasing, stable, or diminishing returns? We cannot answer that question without understanding our return on investment in such research over the past century or more. Yet in our impatient and historically ignorant society policy makers tend to search

for the causes of problems only in the recent past (Watt 1992). One of our greatest challenges is to bring policy makers to understand that historical knowledge is fundamental to contemporary problem solving.

Two roles may be suggested for archaeological and historical research in these matters. The first is to understand if there are regular patterns in the development of problem-solving systems. The age-old idea that a society's problem-solving abilities may decline with time has been noted here but not directly evaluated. To test such a generalization without a framework to explain it would be meaningless. The economics of complexity in problem solving appears to be a promising candidate for that framework. Problem-solving systems do seem regularly to evolve to greater complexity, higher costs, and diminishing returns to complexity. As noted, no system of problem solving that develops in this way is sustainable. In time such systems are cut off from further finances, fail to solve problems, collapse, or come to require large external subsidies. In every case that I have been able to investigate in detail, this pattern holds. This includes the Roman Empire, the Lowland Classic Maya, Chacoan Society of the American Southwest, warfare in medieval and Renaissance Europe, and some aspects of contemporary problem solving (Tainter 1988, 1992, 1994a, 1995, 1996a). We have the opportunity to become the first society in history to recognize the processes by which problem-solving abilities decline and to devise corrective actions.

No doubt there are exceptions to this pattern. It is particularly important that these be found and understood. Following the arguments presented here, it seems that one of the characteristics of a sustainable society will be that it has a sustainable system of problem solving, one with increasing or stable returns or with diminishing returns that can be financed with external energy subsidies of assured supply, cost, and quality.[4] Examples of such societies in history and prehistory should be brought to public attention. Policy makers need to be made aware not only of the problem of diminishing returns to complexity but also of historical cases where its consequences have been averted. The reorganization of the Byzantine Empire during its great crisis of the seventh century A.D. appears to be such a case (Treadgold 1995; Allen, Tainter, and Hoekstra 1999); the earlier phases of industrialism may be another (Tainter 1996a).

This leads to the second role for the historical sciences: to understand where we are in history. Historical processes routinely develop over periods beyond the comprehension of everyday experience. These periods may extend from decades to centuries. Kenneth Watt, for example, has shown how capital investment lags in energy production generate approximately forty-year cycles in price and supply, employment, overall economic well-being, and international relations (Watt 1992). Our current economic conditions, including energy supplies and pricing, cannot be understood if we have not evaluated where we are in this capital investment cycle. We must know where we are in history.

Societies that invest in complex systems with diminishing returns, if they

have sufficient fiscal reserves, productive capacity, and energy subsidies, may be able to finance such a trajectory for centuries before their problem-solving abilities decline significantly (Tainter 1988, 1996a). To comprehend our own situation we may thus need to understand several centuries of our economic history in greater detail than we presently do. It is worth the effort: the first step toward breaking the cycle of increasing complexity and decreasing effectiveness is for our society as a whole to become aware of it.

In the complex of transformations in climate and environment that are known collectively as global change, we may face our greatest challenge. Nothing else in our history equals contemporary global change in magnitude, speed, and numbers of people affected. In the research that we need to comprehend it, in the economic dislocation that it will entail, in the new technologies that we will need, and in increasing government centralization and regulation, global change will require societal expenditures that are presently beyond calculation. This paper suggests that in the past societies were made vulnerable to climate change when such a perturbation came after a period of declining marginal returns to investment in complexity. If this is so, it would be wise for us to understand the historical position of our own problem-solving efforts.

Of course no complex industrial society can be characterized by a single number indicating its return on investment in complexity. The analysis must be done by major sectors of public investment, such as defense, infrastructure, social welfare, medicine, and research. In the research-and-development sector, which is vital to our response to climate change, there are disturbing trends. Some of these trends have been presented here (see figs. 12.2 and 12.3); others are detailed elsewhere (Rescher 1978, 1980; Tainter 1988:99–106, 111–115, 1996a). It would be premature to proclaim that our problem-solving investments in contemporary science are experiencing diminishing returns overall. What is apparent, though, is that the financing of scientific research becomes more and more challenging each year. Science competes for funds with other sectors of public investment. It also appears to require, as Rescher has suggested (1980:92), continually increasing expenditures to maintain a constant level of production of new knowledge. This suggests that, in the current strained fiscal situation, responding to global change may lower the industrial standard of living, as resources will have to be allocated from other public sectors into research and development (Tainter 1988:212, 1995, 1996a).

Our citizens and our policy makers are socialized to have such confidence in scientific problem solving that global change generates widespread complacency; few are aware that research can reach the point of diminishing returns and become ineffective. We do not know if we have, or if we must yet develop, the financial resources, energy supplies, and problem-solving abilities to respond to climate change. The research to determine this has not been done. Indeed the need for the research has scarcely been acknowledged. Yet one of our great advantages over societies of the past is that it is

possible for us to learn where we are in history. The historical sciences are an essential aspect of being a sustainable society. To know this and not to act on it would be a great failure of our efforts to comprehend global change.

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Notes

1. *An Essay on Man* (1732).

2. Within this definition it is appropriate to talk of the collapses, for example, of Mycenaean Greece, the Western Roman Empire, or the Southern Lowland Classic Maya. In each case, an established level of political and economic complexity was abruptly terminated, leaving in its wake societies organized at lower levels of complexity and with smaller populations. The demise of a system such as the Soviet Union, on the other hand, is not a collapse but rather a shift in regime and boundaries. The level of complexity in the countries of the Commonwealth of Independent States is not significantly different from what it was formerly.

In an earlier study I advanced a characterization of social complexity, which I wish to adopt here:

> Complexity is generally understood to refer to such things as the size of a society, the number and distinctiveness of its parts, the variety of specialized social roles that it incorporates, the number of distinct social personalities present, and the variety of mechanisms for organizing these into a coherent, functioning whole. Augmenting any of these dimensions increases the complexity of a society. Hunter-gatherer societies (by way of illustrating one contrast in complexity) contain no more than a few dozen distinct social personalities, while modern European censuses recognize 10,000 to 20,000 unique occupational roles, and industrial societies may contain overall more than 1,000,000 different kinds of social personalities [McGuire 1983:115].
>
> (Tainter 1988:23)

3. Nikolai Danilevsky, a Russian writer and biologist, was a promoter of Slavic nationalism. His *Rossiya i Evropa* (Russia and Europe), published in 1869, employed organic reasoning to predict the decline of Western European civilization and the rise of a Slavic one.

4. For the concept of energy quality, see Hall, Cleveland, and Kaufmann 1992.

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Chapter 13

Land Degradation as a Socionatural Process

S. E. van der Leeuw and the ARCHAEOMEDES Research Team

The ARCHAEOMEDES Program

This paper briefly presents some of the issues raised by the ARCHAEOMEDES Program, the first major European Union–sponsored research program on environmental issues in which archaeology plays an important part.[1] In a period in which most research on environmental matters is oriented toward the natural dynamics of our surroundings, the long-term perspective offered by archaeology has prompted us to focus specifically on the relationship between human populations and their environment. To do so, we have chosen land degradation as the central issue.

Arguing that one of the most general ways to dissect complex phenomena such as land degradation would be to identify the different temporal rhythms that together compose their overall dynamics, we have chosen to compose an ensemble of case studies that reflects the widest possible range of temporal scales. Thus we included scales ranging from tens of millennia (ca. 20,000 to 4,000 B.P. in Paleolithic Epirus) to millennia (ca. 10,000 B.P. to the present in a diachronic study in the ancient Rhône Valley and ca. 5,000 B.P. to the present in the case of the Vera Basin), to centuries (100 B.C. to 500 A.D. in a synchronic study of the ancient Rhône Valley, and 1800 A.D. to the present for the modern Rhône Valley), to decades (1950 to 1990 in the Argolid and in present-day Epirus). From a perspective of spatial scales, the various case studies also cover a wide range. The largest area we considered is the Southern Rhône Valley, closely followed by Epirus. The Argolid is much smaller, as is the Vera Basin.

Perhaps most interesting is what we have learned by contrasting different scales of observation in each of these zones. In Epirus, we studied both the Paleolithic and the recent period at the scale of the whole region, the Ioannina Prefecture, and at that of different, smaller zones within this, all the way down to the single village level. In the Rhône Valley, we looked both at the major phases of degradation during the last ten thousand years and at the social phenomena occurring since 1800 for the whole area. We undertook

detailed studies in a sample of regions within the valley. By contrast, we studied the Vera Basin and the Argolid at one scale only: that of the whole catchment basin, with a focus on the valley.

Environmentally, the areas differ considerably. This is best understood if we briefly describe them on an axis from south to north. The Vera Basin, in southeastern Spain, is badly degraded to the point that badlands dominate and very little vegetation is left. Drought is a severe problem, as are flash floods; the area has many characteristics of a desert and indeed is qualified as such from a climatological point of view. Here, the focus is on a long and detailed series of data on the environment and human behavior that has allowed us to describe in detail the interactions among geology, climate, vegetation, hydrology, erosion, and human activities, to analyze the acceleration and deceleration of degradation, and to unravel the way in which periodicities of different (human and environmental) patterns combine. In the Argolid, in the southern Peloponnese, water (mis)management is responsible for the specter of rapid and total degradation by salinization in the very near future, but for the moment this has only affected small valleys; the remainder is green. The shortage of water is a function of the kinds of (irrigated) crops planted rather than linked to climate. In Epirus, situated in the mountains of northwestern Greece, in a zone with sufficient rainfall, there are two kinds of degradation. One is very long term and omnipresent at the local level, linked to tectonic activity. The other is no less present but operates on a larger spatial and shorter temporal scale; it is linked to the vegetation. We studied both, on a very long as well as a short timescale. In the Rhône Valley, present-day degradation is closely linked to urbanization and its accoutrements, but we have found several major phases of earlier degradation, from about seven thousand years ago onward, which cannot be explained in the same terms because at that time the nature of human impact was very different.

Anticipating for a moment the remainder of this paper, the first, tentative result of our case studies is that we cannot possibly identify a single set of natural dynamics that can be held responsible for land degradation, but it is possible to explain the instances studied as the result of a set of converging social processes that seem to occur in any society, albeit on different timescales. We are not yet able, however, to argue whether such an explanation is both necessary and sufficient.

A Framework Focused on Socionatural Relations

Land degradation risks being lost in the black hole between the natural and social sciences unless a perspective can be developed that manages to subsume the points of view developed in a number of disciplines. Our efforts have therefore been directed at exploring the possibility of placing the so-called dissipative structure paradigm in such a central role.

Our perspective is characterized by the following assumptions with methodological implications:[2]

- The timescale best suited to observing and analyzing complex phenomena is the long term, because of the interaction of processes with very different rhythms. In the case of land degradation, these range from millennial (e.g., tectonic and geological processes), via secular (i.e., the Ottoman occupation of the Balkans), to seasonal or annual (e.g., cultivation and grazing), as well as to momentary events (such as the accession of Greece to the European Union).
- The approach best suited to the study of land degradation is a multidisciplinary one that jointly investigates social and environmental aspects and views the interaction among the different aspects of such a complex system as a coevolution of all the processes concerned rather than in terms of the evolution of some sectors and adaptation of others.
- To study fruitfully the evolution of complex systems, including land degradation, it is essential to develop a fully dynamic approach: that is, rather than assuming stability and explaining change, one needs to assume change and explain stability. Maybe the difference is best expressed by substituting the term *resilience* (the capacity to lead a continued existence by incorporating structural change) for the more common *sustainability* (the capacity to continue as is, without any structural changes).
- Human social dynamics differ from natural dynamics (including those of plant and animal communities) in terms of the role played by information processing. Within one generation, humans can bring about structural changes in the social dynamics in which they are involved. This is due to the human capacity to learn how to learn, which is in turn based on the capacity to organize information hierarchically and symbolize it abstractly.
- Human perception is a fundamental source of dissymmetry in the interaction between human actors and social processes, on the one hand, and, on the other, nonhuman actors, including such major players as the soil, water, the sun, and so on.
- Because of the complexity of many socioenvironmental systems, the degree of coherence of such systems is relatively limited (or, conversely, their flexibility relatively great). This is particularly the case where dissymmetry at the interface between natural and social processes is important. As a result, sudden changes in the order of magnitude of some of the parameters are rather frequent, so unpredictable, or apparently chaotic, dynamics occur. Such systems are therefore said to be nonlinear and metastable.
- To understand the dynamics of such nonlinear systems, a detailed knowledge of the interaction among different spatiotemporal scales is essential. Such interaction is reciprocal: the interaction between entities at the lower level generates patterns at the higher scale that in turn constrain the individual entities' interactions.

- In understanding such complex dynamics, the role of modeling is to test theories by implementing them in dynamic fashion on the computer and then compare the results of simulations with the data available. The models that we have used should not be viewed as representations of reality.

How do these assumptions relate to each other? In a nutshell, we take as our point of departure that the existing dichotomy between cultural and environmental archaeology needs to be abolished, that from an open systems perspective one cannot make a distinction between the environment and the people whose environment it is or between different ecosystems. All that we have to work with are socionatural relations that, for the sake of expediency, can be looked at in morphogenetic (nonlinear) systems terms (McGlade 1995). Such socionatural relations are driven by many different kinds of dynamics, occurring with varying degrees of dependency within and between the two realms: the natural and the social. In the realm of earth, water, wind, and fire, these dynamics uniquely concern the flows of energy and matter, whereas insofar as they concern plants and animals the role of flows of information is limited. Within time frames determined by the lifespans of individual organisms, they are confined to stimulus-response and behavioral optimization, whereas over longer periods genetic transmission of information may induce structural changes. Only in the case of human beings may the exchange of information result in structural changes within the lifespan of the average individual.

As we will see, another important difference between social and natural systems is that although the human impact on the environment is as immediate as that of other species, the human reaction to environmental change—whether ultimately the result of human activity or not—is less direct because it is necessary for a society to become aware of environmental problems before it can consciously respond to them. Such awareness is the result of a conjunction of both environmental and social dynamics, and interaction between them takes the form of resonance rather than direct cause and effect.

What actually happens over the long term as the result of such interaction is far from straightforward. The study of a large number of examples of long-term coevolution of groups of people and their environment, however, seems to point to (at least) one firm conclusion: exploitation by a sufficient number of inhabitants eventually so modifies any environment that at some point the socionatural dynamics necessarily undergo a thorough transformation. The last part of the road toward such transformation is perceived by the people involved as a degradation of the environment: a failure of the environment to answer their expectations. To close the circle, it seems that the study of one aspect of this phenomenon, land degradation, will bring us closer to understanding the character of socionatural relations in general, as well as shedding some light on a problem with important implications for the sustainability of the world as we know it.

What Is Land Degradation?

We will first examine some of the issues that land degradation raises. For example, it has to be stressed that it may occur anywhere; it is not limited to particular natural circumstances such as drought. In Papua New Guinea, for example, degradation occurs massively in tropical rainforests as soon as the local population cuts down the slope forests, a traditional subsistence technique. Scotland and Iceland are examples of equally heavily degraded areas in temperate and wet, or even circumpolar, climes. The Vera Basin in southeastern Spain is now heavily degraded, with sheet and gully erosion and badlands formation, yet archaeological research has shown that at several points in the past it was a wealthy and intensively settled area, only to be degraded again and then heavily exploited once more several centuries later. Sometimes land degradation is not visible until it is too late. The Argolid is a case in point. It looks like an immensely wealthy agricultural area, yet we know that it cannot sustain its present exploitation regime for much longer because soon the water table will have been lowered beyond recovery.

Potentially, land degradation occurs anytime; it is not limited to the present, as we know from many cases in the past. Southeastern Spain, the Syrian desert, the Yucatan, and the southeastern United States were all at different times able to sustain major settlements, even cities, that have now disappeared. Degradation is a perfectly normal occurrence with which people have dealt for millennia. It is moreover a temporary phenomenon in most cases, though the timescale may be very long. Although climate as well as soil conditions, vegetation, and related physicochemical and biological processes play an important part, there is a case to be argued that in view of the variety of circumstances under which degradation occurs—circumstances that share only the fact that human activity has locally modified the ecosystem—the responsibility for many cases of degradation must firmly be placed with human activity rather than the environment.

Erosion is often seen as the sign par excellence of land degradation, and occasionally the two are even conflated. That seems too simplistic. For example, land degradation may include an increase of vegetation, such as in the *garrigue* areas (areas that support low, thorny secondary vegetation) around the Mediterranean or in Epirus. Our definition should therefore be wider, including a variety of physical, chemical, or biological changes in a landscape. But not all such changes qualify as degradation. In actual fact, the term contains a value judgment, in that *degrade* means "to become less in quality."

There are probably as many definitions of degradation as there are of culture. We agree with such authors as Barrow (1991:1) that it is a concept very difficult to define, though most people intuitively have some idea of what it means. We deliberately conceive of degradation as an aspect of the relationship between people and nature, and we argue that for a proper understanding of the phenomenon, study of the interaction between the social and

natural domains is essential. One way to paraphrase degradation from that point of view is to define it as a general measure of perceived loss of suitability for some specific form of (potential) human use.

Such a definition implies that the physical changes modify something that was perceived in a certain way. And the fact that the changes are for the worse further implies that this perception is in relation to a purpose: because of degradation, it is less easy to fulfill that purpose. An unexpected implication is that degradation relative to one purpose might actually make an area more suitable for another: a dilapidated factory complex in an English inner city is degraded with respect to its original industrial purpose but may make a very good playground for children (an example chosen, by the way, to make the point that degradation applies to all aspects of our environment, not only the natural ones).

To establish whether land degradation is occurring, it is necessary to have detailed information concerning a wide range of phenomena in the past, present, and future. Even if the present is accurately documented, the necessary information on past and future is often lacking or insufficiently detailed, or it does not go far enough back in time. Some of our effort must therefore be devoted to establishing a baseline by determining when, in any particular case, land degradation first began. In explaining the phenomenon, the debate on land degradation has generally followed trends that can be pinpointed in the wider literature on the environment. Initially, we see a shift from environmental determinism, via Malthusianism, to any of a range of social, economic, or political explanations (summarized in Barrow 1991:15–21, and table 1.1). What is crucial from our perspective is that most of these explanations identify one or at most a limited set of causes, and build a chain of causation linking land degradation to faraway ultimate causes rather than arguing why these, and not other, parameters are important, or looking at (land) degradation as a phenomenon attributable to a multiplicity of causes. We have chosen the multicausal approach.

The first thing to be aware of with respect to land (and other environmental) degradation is that it involves human beings in two different ways: as actors and as observers. The active role of humans in degradation has increasingly been acknowledged in the scientific literature, but its scope and nature are far from clear and open to debate. It follows from our definition that degradation affects human action; degradation may force people to change their relationship with the land, for example, when a particular plot is no longer capable of providing sufficient nutritive elements for a crop or when the soil disappears through erosion. In this respect, human beings are *reactive*.

It is much more difficult to assess the role of human action in causing environmental degradation, the *active* role of humanity. Many have argued that it seems as if the only thing that most observed instances of degradation share, even if they occur under a wide variety of environmental circumstances, is the fact that human beings were present. To falsify the hypothe-

sis that land degradation is commonly caused by human activity is virtually impossible because that would require us to have sufficient examples of degradation that are, and demonstrably always have been, outside the human sphere of influence. The chances are small that such examples will ever be found on a globe that has been inhabited for hundreds of thousands of years and has been subjected to sedentary human colonization for at least the last ten thousand years and to intensive human pressure for at least a century and a half. Whether degradation can also be due to natural causes alone in cases other than catastrophic events remains therefore an open question. In our opinion, however, such cases are rare, and we will not be concerned with them.

Still, although it is at first sight a plausible hypothesis that degradation is somehow causally related to human presence, there are major difficulties in founding such a hypothesis in scientific research, in proving that human beings are normally involved as actors in triggering degradation dynamics. The processes are so complex, our insights into them so limited, and the number of instances studied with sufficient detail so few and far between that any argument to this effect would be severely hampered by underdetermination of the theories involved, that is, by a lack of sufficient observations to exclude all other possibilities. Parenthetically, this seems one of the areas of degradation studies in which paleoecology and archaeology have an important contribution to make (Barrow 1991:4).

If we look for a moment at the converse issue—whether all human activity leads to environmental degradation—we immediately find support for such a hypothesis in the camp of the romantic environmentalists. But there seem to be a number of arguments against it:

1. There are many cases, notably in the past and in remote areas, in which socionatural exploitation systems have been sustained for hundreds or thousands of years without interruption (but with changes). The terrace irrigation system used in the eighth to fifteenth centuries by the Moorish populations in southeastern Spain is a case in point. The stable long-term exploitation strategies of Andean peasants seem to be another example.
2. The structure of most such systems has been destroyed in the last century or so, and we can therefore no longer study them in operation. Thus we are hampered both conceptually and in our data collection.
3. No discussion of degradation or sustainability is valid without specifying a set of spatiotemporal scale(s).
4. Much current research concerned with the environment searches for ways to attain sustainability, i.e., ways to be able to continue living as we do, ideally forever. Such an approach rests on the fundamental assumption that stability is natural, as well as humanly achievable. A long-term perspective, however, suggests that stability is an illusion that disappears when one chooses a scale of perception commensurate

> with the phenomena under investigation. We thus argue that stability is the exception and that it, not change, should be the focus of investigation.[3]

Because environmental degradation is related to a particular use or function of the environment, one might well expect that in certain cases degradation with respect to a particular use might improve suitability for other (immediate or future) uses. Sowing nitrogen-storing plants at regular intervals on land otherwise used for cereal cultivation is one example; refurbishing dilapidated dockyards as shopping centers and/or amusement arcades is another. But this argument only implies that every degraded cloud has a silver lining, not that there are human actions that do not degrade.

If we shift our perspective for a moment to the involvement of human beings as observers who define what constitutes degradation, we quickly become aware that this aspect of the problem has generally been ignored altogether: few scholars have taken into account the fact that degradation is always a perceptual category, that it has as much to do with perception as it has with the phenomena perceived. Not only are there major differences from culture to culture, such as between the Argolid and Epirus or between these two areas and northwestern Europe, but within a culture what spells degradation for one person may well be an improvement for someone else. Acknowledging this does not make our task any easier, because it implies that if we are to understand degradation we have to take into account dynamics that are notoriously difficult to qualify or quantify. But perception seems to play such an important role that ignoring it requires one to accept a heavy dose of reductionism.

Finally, the nature of the dual involvement of human beings in degradation dynamics, as actors and as observers, poses its own problems. Notably, it begs the question: Can we, with respect to degradation, maintain the distinction between humans and all the other species inhabiting the globe? Our problem is insoluble as long as we do. The growth of a pine forest suppresses the chances that other vegetation will grow underneath it; in a sense, therefore, the pine forest has degraded the environment for a large number of other species of plants. What distinguishes this kind of degradation from the kind we have been discussing so far is the fact that in the case that concerns us humans have degraded the environment for humans, while the pines have degraded the environment for nonpines. Or have they degraded it for pines as well? In a certain sense they have, because once a certain density of pine trees has been reached, no others can grow there for lack of light. We must conclude that degradation is not exceptional as soon as we accept that humans are in some ways like all other species and that it causes particular problems for humans only because of the reflexive capacity of human cognition, because we think we can do something about our own behavior.

It is with these issues (and others) in mind that we have conceived of degradation as a phenomenon that can occur as a result of a conjunction of

circumstances, natural and social, as soon as one or more variables accelerate or slow down out of proportion, not allowing the other (articulating) ones to keep up with them and thus causing a search for a different dynamic equilibrium of the total system. The implication is that as soon as one or more variables are out of step, the dynamics change, and such a change manifests itself, at least to some of the participants in the system, as degradation. Four advantages of such a definition spring immediately to mind:

1. The definition addresses the dynamics behind the observation of degradation, rather than the observation itself.
2. The definition is a very general one applicable to land degradation but also to other forms of degradation.
3. The definition can be applied within different disciplines provided the paradigms involved allow the use of a dynamic metalanguage, as most disciplines do.
4. This formulation implies that we shift from a perspective in which we distinguish stable states and transitions to one in which change is permanent and stability only relative, a term to be applied on the basis of a comparison with observations made before and/or elsewhere.

Within such a perspective, then, degradation becomes a qualification that may be given to certain, but not all, perceived changes in the structure of a dynamic equilibrium, a transition between two or more different dynamic behaviors and/or a move of the dynamics from one set of structuring parameters to another. This introduces a link between observed qualitative change and (generally unobserved) quantitative changes in the dynamics concerned, the latter deemed to be irreversible within the spatiotemporal horizon of the human actors. This again stresses the importance of timescales in the study of degradation.

The Asymmetry of the Relationship Between Societies and Their Environments

It follows from our coevolutionary perspective that, in taking a closer look at the relationship between societies and their environments, we acknowledge that both societies and environments have fundamentally different internal dynamics that impinge on one another under particular circumstances. Borrowing a neologism that has become popular the last few years, one might say that there are particular windows of opportunity in which the respective dynamics of these two domains have independently brought the two realms to a point where they can directly affect one another.

It is our contention moreover that the relationship between the two realms is asymmetric, in that both society's perception of the environment and its impact on it are governed by the filter of human perception. In this paper we will focus on that asymmetry, dealing more specifically with some

aspects of the dynamics of human perception and information processing and their development over shorter and longer timescales.

Perception and Cognition

If we are to distinguish humans from all other species in the coevolution that is nature, it must be because humans are different, not just because we want to feel special. In the present context, one way to establish this is to argue (a) that human beings can not only learn (as do other mammals) but learn how to learn (Bateson 1972), and (b) that human beings make artifacts, i.e., transform matter and energy according to ideas (Strum 1987). Both these capabilities are derived from the human capacity for perception (and cognition, which for simplicity's sake is included under perception in what follows). Therefore that should be our starting point.[4]

Underdetermination. Our selection of accepted observations is to a large extent preprogrammed, because of cognitive structures acquired earlier. Thus when we move into a landscape, our treatment of it is initially mostly determined by our knowledge of the landscape(s) we dealt with before. Flying over the western United States, for example, we see a checkerboard pattern of roads totally unsuitable for mountainous landscapes that was developed for the Great Plains. Similarly, it is arguable that the destruction of the New England forest after European settlement was to a much greater degree due to its being subjected to a different perception and consequent approach to forest exploitation that destroyed small but essential elements of it than to wholesale overall destruction (Cronon 1983).

These and similar cases point to the fact that much of our perception is underdetermined by observation and overdetermined by the preexistent cognitive structure that determines our definition of problems. Atlan (1992) argues that this is a general characteristic of human information processing, a result of the combinatorics of the relationship between observations and theories to explain them. Take, for example, five elements (traffic lights) that can each assume three states (red, yellow, green). The total number of combinations observable is then three to the power of five, or 243. But the number of possible connections between the lights is five to the power of two (25), and the number of possible connection structures (theories about the connections) three to the power of twenty-five, that is, about 1,000,000,000,000. It follows that we would need billions of observations to have all our theories (even about such simple things as in our example) derived predominantly from observations.

It is only with time that we learn about a landscape. Such learning usually begins with a positive assessment of the potential of a landscape that accentuates the opportunities seen by people who have evolved their landscape perceptions in different contexts, elsewhere. Perceptions of the landscape's limitations surface only later, but these are no less related to the perspectives of the people involved. When they do perceive limitations, the people concerned

have usually already made a major investment in their relationship with their environment and will thus tend to modify their ways of organizing or exploiting it rather than develop an entirely new perspective.[5]

The changes in the perception of the landscape and its potential, and in the limitations discovered, are inherent not in the landscape concerned but rather in the way they are perceived and the evolution of that perception. This shift may be explained by having a closer look at the nature of perception itself.

A model of individual perception. Perception may be defined as the awareness of uniformity (similarity, continuity, homogeneity) and of contrast (dissimilarity, discontinuity, heterogeneity). Evidently, uniformity and contrast are relative to one another and can only be perceived in conjunction. To do this, human information processing always operates at two levels: the level of context, which stresses underlying similarities, and the level of the specifics, which stresses dissimilarities (Bateson 1972). Following a range of experiments, Kahnemann, Tverski, and their associates (see, e.g., Tverski 1977; Tverski and Gati 1978; Kahnemann, Slovic, and Tverski 1982) have concluded that similarity and dissimilarity should not be taken as absolutes. Categorization occurs by comparing a subject to a referent; here, however, the emphasis on either similarity or dissimilarity in a comparison is determined by the direction the comparison takes. If the context is compared with the phenomena under study, the comparison will emphasize similarities, but if the phenomena are compared with their context, differences are highlighted (fig. 13.1).

Maybe one of the interesting consequences of this work is best introduced by pointing to an essential difference, in French, between *le milieu*, that

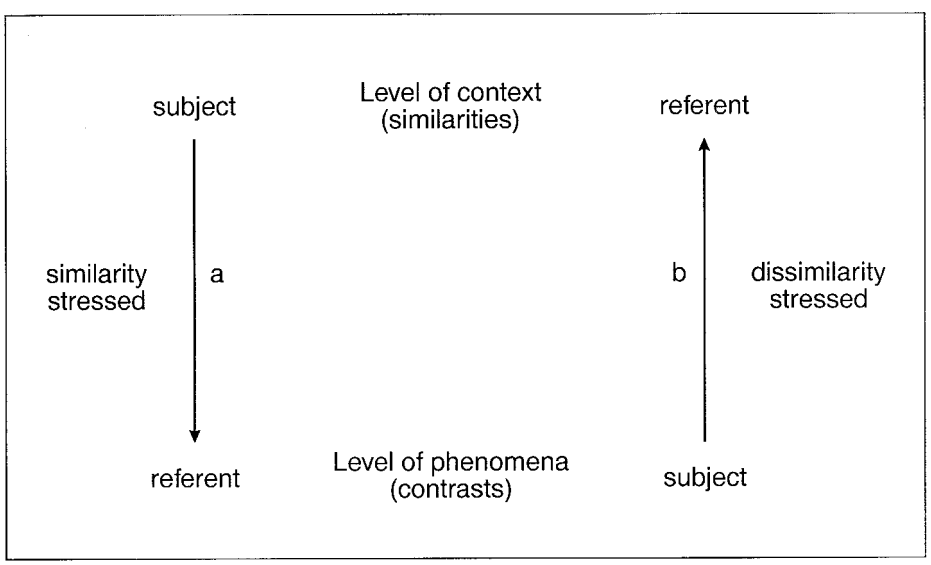

Figure 13.1. Schematic model of perception.
Based on Tverski 1977; Tverski and Gati 1978; and Kahnemann, Slovic, and Tverski 1982.

is, "that which human groups are in the midst of," and *l'environnement*, "that which surrounds human groups." In the former case, although the focus is on what surrounds human beings, the perspective is human, whereas in the latter case, the perspective is decidedly nonhuman. In the terms of Tverski and his colleagues, the former concerns a perspective in which human beings are the subject of the relationship and the surrounding nature their context, so that the differences between the two are stressed. Humanity is viewed as passive, and nature as active and aggressive. The term thus emphasizes the cohesion, the unknown aspects, the strangeness, and the force of nature. Change is attributed to nature, and humanity has no choice but to adapt. From this point of view, natural dynamics are deemed dangerous, because they cannot be controlled by human beings.

In the *environmental* perspective, on the other hand, nature surrounds humanity, and the comparison is between nature as the subject of the relationship and humanity as the context, so that the similarities are stressed: the cohesion and strength of nature are reduced, and humanity's amplified. The known aspects of nature are stressed, and the environment therefore seems easier to influence and control and loses its dangerousness. In this view, humanity is seen as the source of transformations, as the creator of its milieu.

A very simple example may clarify some of the implications. What would be called degradation from the environmental perspective could, equally justifiably, be described as the socialization of the milieu from the other. There is thus a (poorly defined) area that can be (and is) studied from both a human and a natural perspective, in which all (or most) of the essential interactions between a society and its natural environment are played out.

On the basis of Tverski et al.'s conclusions, one can moreover argue for a continuous two-way process between information and the information-processing capacity that entails a feedback cycle in which the self-reproduction involved is never exactly identical. Such a cycle might then be held responsible for slowly shifting the human evaluation of a socionatural system, driving it from happiness, via satisfaction, to incipient dissatisfaction and eventually to such a negative attitude that fundamental changes in the system become inevitable.

Suppose for a moment that an initial situation is experienced as involving little or no friction between the human and nonhuman components of the system. In such a case, the first iterations of the cognitive loop only register as a minimal shift, and although with each subsequent iteration the bias will imperceptibly shift, the overall sense is one of harmony between the individual and the environment. Slowly, perception will then move toward a balance between similarity and dissimilarity, a perspective in which both positive and negative elements of the socionatural coevolution are acknowledged. Once dissimilarity dominates perception, each iteration will cause increasing dissatisfaction, so that the basis for the original system will slowly be whittled away. This would be experienced as a loss of quality in the environment: degradation.

Eventually, there will come a point when an iteration results in a qualitative change, a new approach to socionatural interaction. But just before such new perceptions and approaches are generated, there is a period in which the old system no longer functions satisfactorily. It cannot deal with the socionatural dynamics any longer, mainly because each comparison between the natural dynamics and the human perception thereof indicates what the observed phenomena are not. This point might rightfully be called an environmental crisis.

Group perception. In most situations the human impact on the environment is that of a group of human beings. We must therefore also look at the impact on environmental perception of the fact that humans are social beings.

In *Ecological Communication*, Luhmann (1985) views society as a self-organizing (social) system of communications based on a complementarity of expectations among individuals. These expectations are guided by meanings that in turn relate exclusively to other meanings, and their constitution prepares the way for further communicative alternatives. Communication is seen as the common actualization of meaning, the reduction of the complexity of social interaction through the harmonization of the actors' perspectives. Everything that functions as an element in the communications system of a group is therefore itself a product of that system: it is self-referential. As a result, societies cannot communicate with their environment; they can only communicate about their environment with each other.

There are here some very pertinent consequences for our study of socio-environmental dynamics. We have seen that one cannot consider nature and culture as separate subsystems. The two spheres are in fact inextricably intertwined (McGlade 1995), and their separation in the Western intellectual tradition is the result of the particular cultural history of fourteenth-century Western Europe (van der Leeuw 1995). A simple but relevant example that we often forget is that resources are not simply natural. Anything in the environment of human beings is a potential resource for a group of humans, but only perceived and socially negotiated resources can be exploited. The choice is of course anchored in what social anthropologists call culture and technology students tradition. The members of any group share in these differentially.

The difference that here concerns us is between innovators and exploiters. This, simply put, is responsible for the dynamic tension that allows the group to successively discover and exploit different resources and in so doing determines the group's resilience as well as the environmental degradation it perceives (and causes).

How would the two—innovators/discoverers and exploiters—interact? Ideally, the former would make a discovery, and then the latter would jump on the bandwagon and apply the discovery for a long time. Once the resource(s) involved diminished, they would become dependent on the innovators again to find them a new source to exploit. The society as a whole would thus at any time oscillate between at least two strategies.

One of the implications of this dynamic cycle is that a society and its material manifestations are linked in a continuous interaction that simultaneously produces the society's material culture, its organization of space, its exploitation of the landscape, and so on. A second one is that such self-organization is responsible for the uniqueness of both each cultural tradition and its material context (Touraine 1977). But from a dynamic perspective, there are three other corollaries that are less manifest.

First, any group's social organization (and its dynamics) interact with the dynamics of the environment, natural and cultural. The dynamics of the group may amplify or dampen the dynamics of the environment according to the internal workings of the society and the delays inherent in socionatural interaction (delays that vary with the size and shape of the organization).

Second, even after feedback the response is always less than optimal because the response only takes into account what was known at the time of learning and not what ought to be known at the time of action to deal optimally with the problem involved.

Finally, in the vulnerable phases that occur when the change in the environment is interactive with that of the organization, the group's way of dealing with things (including the environment) may be resilient (i.e., it may incorporate change in order to maintain continuity), but this is not necessarily so.

Whether the group is resilient or not will to an important extent depend on the dynamics of the environment itself. If these move within the range of variation that has normally confronted the society, or not too far beyond it, the group will probably be able to deal with the situation. But if the environmental phenomena are of the centennial or millennial kind, then the chances of an effective response are much less. Under such circumstances, there is an element of chance involved, as the speed with which the society invents a solution becomes crucial. If the solution is not invented within a reasonable time, determined by the society's momentum, then the whole dynamic structure may lose momentum.[6]

The extent of a group's collective memory is thus of vital importance to its survival at such moments in its history: if it is diverse and encompassing, the society has a better chance of finding a solution before its time runs out than if it is either very limited or homogeneous. That in turn explains the fact that many societies have invented ways of enhancing the effectiveness of such memory, whether by naming children after major environmental events (see, e.g., Togola and McIntosh, both in this volume) or by keeping lists and descriptions of such events in writing, usually in a sanctified context, as was done in Egypt or China (see, e.g., Hassan and Hsu, both in this volume). But it also relates to the importance of maintaining a degree of diversity, not so much in the natural environment itself as in the group or society's range of ways to deal with that environment. We see this reflected in Dean's stress on the importance of maintaining the suboptimal strategies of dealing with a landscape (see his contribution to this volume), as well as in Crumley's perspective on the role of the garden (also in this volume). We

should consider not only the resilience of the environment but also that of the society itself, as well as that of the articulation between the two.

The Output: Risks and Unexpected Consequences

A society (or an individual) does not only perceive its environment; it uses perception to conceive and execute actions that have an impact on it. In so doing, it continually makes choices among a number of physically possible options that it perceives. In that process, social negotiation is of major importance. And any course of action that is chosen changes the environment not only in evident ways but also in hidden ones.

The interaction between human beings and nature may be paraphrased as *information of substance and substantiation of form*. It consists—again—of a loop, this time between the ideal and the material realms. In moving from the material to the ideal, perception reduces the number of dimensions (a reality is transformed into [a set of] symbol[s]), whereas in moving from the ideal to the material, dimensions that do not exist in the realm of the ideal (i.e., that were thus far unknown) are introduced into the material world. This loop affects the resilience of any socionatural system by changing the risk spectrum of the interaction between the society and its surroundings.

Effective knowledge of the environment does not extend itself beyond the time span over which an individual (or a population) retains a sufficiently accurate memory of observed phenomena. Perceived risks are therefore usually relatively short term. Attempts to attenuate such risks, including any actions that affect the environment, introduce new risks by changing the environment. Some of the new risks are—again—characterized by relatively short temporal scales and will thus trigger further adaptations, while others will remain hidden for considerable periods. The net effect over a longer time span is thus a cumulative transformation of perceived risks (operating at the shorter timescales) into risks with delayed perceptibility, operating at longer timescales. Eventually, these will tend to accumulate at particular spatiotemporal conjunction points and lead to environmental crises such as we are observing all around us. The position of these conjunction points is related to the traditions/culture involved and should therefore be theoretically predictable given enough knowledge about a culture.

This argument reinforces our idea that human dynamics are (in part) responsible for environmental crises, even in those cases in which causality is not directly demonstrable. The uncontrolled accumulation of longer-term risks will always undermine a system, presenting a population with what seems to be a crisis brought about by changes in the environment but is in actual fact due to human behavior and notably to choices made a long time in the past.[7]

An example from Papua New Guinea. An example from Papua New Guinea illustrates the impact of perception on interaction with the environment. In the Western Highlands, the general tendency among many tribes is to view any kind of change as degradation and to idealize a stable past.

Moreover these tribes believe that one can correct problems by, as it were, going back (ceremonially) to the point in time where the root of the problem lies and sorting it out. In the case of the Huli, which we know very well through the recent work of Ballard (1995), we can follow the development of degradation through time (Ballard has patiently unraveled the oral history and genealogy of the tribe) and glimpse the history of a population that is slowly retracting from the hillsides into the valley and the swamps that predominate. Thus a population initially concerned with having water flow over their fields became one concerned with draining it out of those fields. How could that have come about? Detailed research presents the following picture: observing some degradation, the need for a ceremony is felt necessary to reestablish the equilibrium between people and nature. Traditionally, such a ceremony requires feasting, notably on numbers of freshly killed pigs. The more frequent the ceremonies, the greater the need for pigs and pig feed. This leads to an expansion of the area devoted to horticultural activities, which is only possible by cutting down the forest. As in many parts of Papua New Guinea, settlements are preferably located on hilltops and ridges. The slopes are steep, and erosion follows rapidly under the tropical rains as soon as the area cut down exceeds a certain threshold size. Slowly, the population cuts away the means of subsistence that surround it and is forced to move downhill. Eventually, their concern to keep the environment as it was in the past totally transformed that environment and landed them in the marsh that is (in part) the result of all the soil that washed downslope.

An example from Europe. In this context, it is interesting to reflect for a moment on what is happening in the Argolid (Lemon, Blatsou, and Seaton 1995). Here, people currently speak of an environmental crisis because there is not enough water to continue irrigating the citrus crops that have been planted all over the valley. But the water shortage is itself due to the forty years of intensive citrus cultivation, ever deeper drilling and pumping, and ever more wasteful use of water (e.g., using sprinklers 120 nights a year to ward off frost that is likely to occur only 10 of those nights at most). As a result, the water table has dropped in some parts of the valley up to seven meters a year, and water now has to be pumped at the valley's edge at depths of up to four hundred meters. Clearly, therefore, what was initially seen as an environmental crisis now has to be viewed as a consequence of the use of inappropriate crops and technologies in the area, which was itself driven by applying an industrial perspective to agriculture (citrus fruit requires hardly any labor or investment once the trees have been planted and the irrigation system constructed). What lies at the root of this crisis is the fact that what in the short term was perceived as an ideal match—between the Argolid plain and citrus—turned out to be a mismatch over a slightly longer time frame.

The people who brought this agroindustrial perspective to bear on the exploitation of the fertile lands in the valley came from outside the traditional farming community. They were generally upper-middle-class white-collar workers who became aware that by declaring themselves farmers for

more than 50 percent of their time, they could claim large subsidies enabling them to make the initial investment in citrus cultivation. These subsidies were intended to allow young people from farming communities to set themselves up independently, thus perpetuating their communities. In a very real sense, then, the crisis in the Argolid is also an unintended consequence of the subvention policies of the Greek government and the European Union.

What is an environmental crisis? Plainly, we must redefine the term *environmental crisis*. With respect to environmental matters, a crisis is traditionally seen as an inescapable, large-scale, destructive natural phenomenon. The term owes its ominous sound to the particular perspective that happens to hold sway in Western Europe: humanity is doomed to experience the vagaries of an (alien if not hostile) natural environment (van der Leeuw 1995).

Crises such as these (have) occur(red) in many, if not all, domains in which a social structure maintains itself dynamically through time. Moreover crises occur at all levels of social structure, from the small group to the state or the empire. Indeed it is their universality that has prompted us to hypothesize that, at least in part, so-called natural crises are a social phenomenon, inherent in human ways of information processing.

From the socionatural perspective that we have adopted, one could define a crisis as *a (temporary) incapacity on the part of the members of a society to deal with the dynamics with which that society is confronted or to relate the external dynamics to the internal ones and the state of the natural phenomena involved to the state of the group of human beings confronted by them* (van der Leeuw 1998:ch. 3). Such an incapacity may be due to the absence of sufficient information or of sufficient information-processing capacity or to a mismatch between the kind and amount of information needed and what is available. The mismatch may be of a political, conceptual, or other nature or may have to do with the scale and nature of the phenomena. The society may, for example, lack the technology or the economic or organizational means to mobilize it sufficiently rapidly to deal with the problems involved (Tainter 1988, 1995). The important points are, first, that crisis is not an absolute but a concept that relates the size and nature of certain phenomena to the means at a society's disposal to deal with them. Second, because nothing is ever static in the realm of socioenvironmental relations, any crisis is by definition temporary. And, finally, the solution for a crisis is not to be found in the nonhuman environment but in the society that has defined it because it lacked the means to deal with a conjunction of phenomena.

Information processing and social structure. Another well-known example of an environmental crisis is the so-called tragedy of the commons. In Britain, the common lands of various villages and towns have always served a major role in equilibrating the subsistence economy among individual inhabitants and between good and bad years. All members of the community had access to these (uncultivated, usually wood or grass-covered) common lands and could profit from using anything that grew on

them. When the harvest was poor, the more vulnerable individuals in society managed to survive by leaning heavily on this extra source of food (for man and beast). Over time, however, common lands became overused and degraded. This was because the benefits of overusing common lands accrued to the individual, while the costs were incurred by the group. In such cases, the individuals' advantage is the disadvantage of the community, but, nevertheless, these individuals generally prevail. The problem has been declared technically insoluble by Hardin (1968), because it is in practice not possible to choose between the good of the group and the good of the individuals that make up the group.

But social structure is itself a major factor in the overall construction of the cognitive sphere of the members of a group. In both the Papua New Guinea and British examples, the whole group went down a particularly degrading path without the capacity to do something about it. But there are differences between the two cases. In the former, the degradation is not due to inherent conflicts between individuals and/or groups in the society, while in the latter such conflicts are at the root of the degradation. In order to understand the full significance of this difference, it should be seen in its context.

In the Huli case, the group concerned is a tribe that speaks its own language; it is essentially independent from neighboring tribes and possesses no pronounced and institutionalized social hierarchy. Because there is no hierarchy there is no perceived difference between the individual and the group. As a result, the interests of both coincide. An internal conflict thus cannot lead to the same results as in Britain, but, on the other hand, in a conflict between perception and reality that is shared by the whole group, there is no external point of view that might halt the cycle responsible for degradation. In the British case, by contrast, the village group concerned may be of generally the same order of magnitude, but it is not independent. The people in the village consider themselves part of a hierarchy of entities (parish, district, county, and nation), and in cases of internal conflict, they expect a higher level in the hierarchy to take action. The corollary of that perception is that within the group, hierarchy is also acknowledged as a basis for reasoning. Hence the conflict between individual(s) and group is allowed to exist.

The importance of social structure becomes all the clearer if we include a third example in the discussion, that of Saurashtra (Gujarat, India). Here, the intervention of one higher hierarchical level (the provincial government) enabled the local fishermen to acquire larger boats through government subsidy. This led to overfishing. When the danger became apparent, the elders of the community imposed forty extra (religious) holidays on fishermen. Thus another (intermediate) level of the hierarchy intervened to undo the damage done by the higher one (Patel 1989). It would seem that here the part/whole relationships within the two hierarchies—individuals within the village and villages within the state—are seen as qualitatively different and able to counterbalance each other. At the same time, from a wider perspective, the prevalence of the individual and the importance attached to

his/her interest might be seen as a cultural blind spot of Western culture, imposed on India from the top but not yet sufficiently accepted nearer the local level to be unassailable.

Investigating the role of social structure is a complex business, and many structural characteristics are particular to one or a few societies and therefore not generalizable. But recent research is developing a perspective that allows us to come to grips with some aspects of global structures present in many human societies. It is based on the idea that social structures are essentially self-organizing communications systems.

The Epirus Example

An example drawn from our fieldwork in Epirus may clarify the role that the nature of social structure and communications networks plays in land degradation. Until after World War II, the inhabitants of any Epirote village formed an isolated and closed small group in which the information pool was very homogeneous (everyone knew everything about everyone else) and most activities occurred on a consensual basis. Consequently, the technical, social, and economic differences among the inhabitants were relatively small. The socioeconomic system had been functioning for a long time; people knew the area intimately, and their way of dealing with the environment was therefore closely matched with local circumstance: a long-term sustainable strategy had evolved.

The period just after the war saw the introduction of roads and thus the first contact between many of the isolated villages. As some people started moving along the roads, information from the immediate and more distant outside—stories and observations about how things could be done differently—began increasingly to influence village life. Because not everyone shared the urge to travel, the information pool began to differentiate. At the same time, the roads brought increased meddling by regional and supraregional institutions and linked the villages to a whole range of different hierarchies. The village headmen, for example, became answerable for some of their activities to the authorities in the local town but also gained special status and an information link to the outside that changed their roles in the village.

Considerable outmigration has also characterized the last fifty years, with people earning money abroad but returning regularly to their ancestral villages. This contributed to an acceleration in social and economic differentiation, so that everybody no longer knew everything about everybody else, and introduced occasional conflicts between personal and group interests. This in turn entailed a mental change. For example, where local populations often considered their hilltop villages as their real homes, they now generally consider themselves as living in the valley where they work.

As residence in the valley became longer, grazing on the higher slopes grew less localized. A long-standing prohibition on burning the hillsides—a practice that used to provide grass for the animals—is now being enforced.

By itself, this prohibition would not have any negative effects if the herds continued to graze the same grounds every year; they would simply keep all nongrass vegetation short or out. But under the changed perceptual circumstances, thorny bushes in the uplands immediately expanded, and now part of the uplands is inaccessible, even to goats, forcing the animals even closer together in other areas, which are likely to be overgrazed, leading to erosion on the very vulnerable (tectonically highly active) slopes. Thus outside authority and local changes in perception have colluded to allow garrigue growth, which can be seen as one kind of degradation, and increased gulley erosion where brushwood barriers are no longer maintained.

But increased dependency on valley cultivation is also related to changes in the economy: cash became more and more important as urban ways, norms, and ideals penetrated the countryside and stimulated people to acquire material goods. This in turn created increased dependency on the commercial aspects of the regional (national, supranational) economic system. In the Argolid, which has moved much further down this road, economic integration manifests itself in a predominance of cash cropping, a rapid succession of (fossil groundwater–dependent) monocrops (grape, lemon, orange, apricot) and altogether very strong and rapid oscillations in the system. Comparing the developments in Epirus and in the Argolid, one might raise the question whether the growing contrast between urban and rural lifestyles and perceptions, as well as the growing impact of the former on the environment, is not at the root of much degradation.

Dynamics of Communications Structures

To describe the qualitative dynamics underlying this evolution, we have refined a model we originally developed some years ago (van der Leeuw and McGlade 1993, 1997) to show the importance of the nonlinear dynamics perspective in understanding such complex phenomena. The size limitations of this paper do not permit us to give the full argument, but for the purposes of discussion, the dynamic can be described as an innovation-communication (reaction-diffusion) dynamic interlocking a human component and an environmental component. The former consists of relatively few superimposed rhythms and can potentially be accelerated with relative ease (people can learn), whereas the latter is a very complex composite of myriad different embedded rhythms in all the food webs involved. One might say that in the rural situation the (faster) human dynamic has locked on to the (slower) environmental one: the people concerned have adapted their way of living to the rhythms and dynamics of nature. These dominate the overall dynamic, and natural diversity is what stabilizes the symbiosis between people and their environment: as in most rural environments, change is relatively slow. In the towns, on the other hand, all processes have accelerated. There, the human dynamic increasingly sets the pace for, and thus dominates, the environmental dynamic.[8] Villages and towns also differ

in the relative importance of the two major forms of communications networks that seem relevant to our investigation. Village-level communities are predominantly connected by hierarchical communications networks:

- Family ties are strong, the elders in the family have a dominant role, and much communication remains within the family.
- The majority of people do not communicate much outside their community. Only a few do, those who take responsibility as mayors or as representatives of their communities in regional councils and the like.

These hierarchical networks are very efficient in their use of (mostly local) energy and information (news spreads quickly) but relatively slow to adapt because the decision makers are few and of limited diversity and because the well-being of the group is more important than that of the individual.

In the towns (which are relatively small in Epirus), on the other hand, professional contacts outside the traditional kinship system become more and more important and lead to the development of distributed (or heterarchical) networks that crosscut family and village ties in many different ways. The communications transmitted through these links are different, tied into the commercial activities concerned, and offer alternative means to rewarding social life. They thus contribute to a differentiation of value systems. The links also display a relatively high degree of adaptive flexibility, allowing for an acceleration of change. Their weakness is that they have more difficulty dealing with rapid fluctuations in network size (whether attributable to demographic factors or others).

What happens when urban ideas begin to spread in the countryside? Increasing exposure to the acceleration of the social dynamic—for example, by the construction of roads—seems to lead to a cyclical periodicity in which the nonlinear coupling of the relatively structured, slow environmental dynamic and a more rapid and stochastic human one generates an oscillation between phases in which the dynamic is more structured and catastrophic phases in which it is more stochastic (fig. 13.2). In other words, there begins to be a debate and an alternation between more traditional and more urban ways of thinking and doing.

Ultimately, such oscillation is unsustainable, and the system will inexorably move toward bifurcation. A choice is forced on the community: it can remain rural by isolating oneself from what happens around it (i.e., by severing some of the communications links), or it can allow itself to be urbanized. Although the former choice is of course only a temporary solution, it is indeed implemented by some villages. The result is an increasing separation between hierarchical and heterarchical communications modes (i.e., a growing differentiation between rural and urban lifestyles within and between settlements) and a concomitant differentiation of the landscape into areas that are still governed by the traditional ways of exploiting the land (socionatural dynamics dominated by the slow rhythms of the environment) and

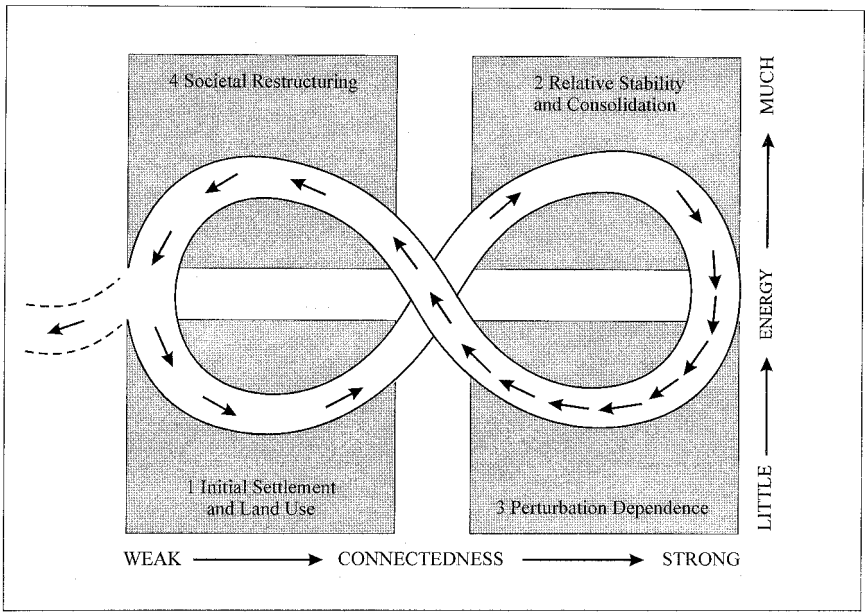

Figure 13.2. Theoretical interaction between a group and its environment. The model assumes continuous, incremental change in the environment and ignores feedback from the group to the environment.

others in which new approaches are introduced, human control over the environment is enhanced, and a quicker pace of change appears.

Such a bifurcation might be triggered by the (highly probable) situation that in some places a more rapid adaptation is required of the total man-environment system than in others; in other words, in some places the total dynamic is more dependent on the human component of the symbiosis than in others. This would, for example, be the case in areas with less diverse ecologies than others, such as areas of poorer soils that might require heavier human investment.[9] But, conversely, in the richest agricultural areas the social dynamic might be what forces the system toward rapid adaptation because people are less resistant to new opportunities. The result is the same, but the dynamic involved very different. Increased spatial separation between the people partaking in the two worldviews would relieve both kinds of communities from the constraints imposed on them by the other one and would thus allow them to grow in those precise environments for which they are best suited.

Communities organized along predominantly heterarchical lines would spread (their dynamic being the more adaptable) and create spatial connectivity over relatively long distances through specific heterarchical corridors. Prime candidates for such corridors or channels would be valleys, roads, coastal waters, and so forth. By implication, the rest of the society would conform to a slower rate of adaptation, through its more hierarchical communications system. This is indeed what has happened in Epirus, where the valleys are the tentacles of the heterarchical network. As we have seen, slowly

but surely the focus of even the most remote hilltop communities has shifted to the valley, bringing about fundamental changes in the economy (which is transformed from a herding mode to one in which the herds depend on fodder cultivation in the valleys) and in spatial organization (with the closure of the upper slopes to grazing).

Once heterarchical systems grow in size they in turn become much less adaptable. An oscillation emerges in which they differentiate into nodes and hierarchize locally. The extent to which each of these new properties emerges is initially variable in space and time. It manifests itself as the acquisition of stronger urban characteristics by some villages, which begin to dominate the dynamics of the surrounding area, and the development of increased social stratification in these larger villages. Both occur, but the degrees to which they do may be crucial in the dynamics. The overall effect is that the encompassing long-distance (heterarchical) network differentiates to some extent, creating room for a degree of local independence in its centers. For a while at least, such uncoupling might allow sufficient localized dynamics within the network to maintain adaptability of the total system.

For the remainder of the development, the reaction-diffusion process and its dynamics no longer constitute a profitable metaphor. The complex socioenvironmental system thus emerging will indeed, before long, explore other basins of attraction and find other sets of overall parameters. Increasing the adaptability within the heterarchical component of the system might, for example, reduce its efficiency, with such reductions initially manifesting themselves as, say, energy crises (misharvests, famines, or other natural disasters that affect the food web on which the existence of part of the network is predicated). Such crises would in turn exert pressure to optimize efficiency in the different nodes, leading to the emergence of local hierarchies within the individual communities on the way to urbanization, and would enhance adaptability of the network as a whole by imposing a hierarchy of sizes on the urban system (Pumain 1997).

Moreover heterarchical systems become much more stable when they differentiate (Glance and Huberman 1997) and will therefore generally see a rapid increase in the extent of task specialization. Rather than each family fulfilling all the roles needed for a successful existence, as is the case in rural systems, individuals specialize and exchange in urban ones. They call for the help of someone when a particular task cannot be done efficiently and either pay them or accept to be in debt, which is acquitted when the roles are reversed.[10]

Another transition occurs wherever being more adaptable has won out over optimizing communications and resources: the system's coherence now comes from its rapid change rather than from its optimization. After all, optimizing the use of any resource demands time (hierarchies have to shed some of their branches/nodes), and it must be assumed that at the rate of change occurring, some hierarchies do not have the time to adapt anymore. So far none of the rural communities in Epirus that we have studied has

made this transition, however, and we will therefore not go into this part of the argument.

Conclusion

This paper presents a personal perspective on the interaction between people and their natural environment and outlines some of the contributions that archaeology might make to our understanding of the long-term evolution of that relationship. The subject of this paper, and of this book, is one that is only beginning to emerge. It is exciting and highly important, as evidenced by the reactions of a range of (scientific and administrative) audiences to presentations of the results of the ARCHAEOMEDES program. But it is born under a heavy cloud, which it will be difficult to lift. Many aspects of our present-day scientific culture discourage attempts to follow the lead this book has proposed. The legacy of positivist science is much more widespread than one would at first sight imagine. It is at once responsible for our disciplinary (and university) structure (which separates communities of scholars on the basis of subject matter), for an approach to the natural world that dissects and studies phenomena (and systems) out of context, and for a kind of logic, based on a rigorous cause-and-effect link, that severely limits our efforts to understand all but the simplest kinds of dynamics.

The opposition between the natural and life sciences, on the one hand, and the social sciences and humanities, on the other, has allowed us to develop important insights into the nature of the two kinds of dynamics involved in socionatural interactions, but it has blocked most attempts to focus directly on the relationships between people and their natural environment. Our own obsession, as archaeologists, with studying the past for the past's sake has artificially thwarted one of the most important and fruitful ways of generating ideas about the past: comparing it with the present. Ecologists and environmentalists alike have been insufficiently alerted to the dangers of predicting the long-term future on the basis of about fifty to one hundred years' worth of observations.

In an era in which archaeology has to fight for its existence as a discipline, however, a quick scan of the subject matter that this book presents leaves one very positive and lasting impression: archaeology can contribute a great deal to a better understanding of both the past and the present if the archaeological community manages to build on its strengths as a multidisciplinary group. By focusing on the long-term dynamics of the many processes that now present us with problems and notably on the socioenvironmental relations fundamental to the existence and survival of our species, we may rightfully claim a place in the contemporary discourse and overcome our past unfruitful attempts to address contemporary problems.

Crucial to that endeavor is rethinking our methodological foundations—our system of collecting, storing, and especially classifying and interpreting

our raw data, which has not evolved since the beginning of the century—so as to maximize the information gathered. Rather than establishing so-called facts, data should be used to infer problems facing past human populations, to elicit alternatives, and to determine choices made among them. Rather than separating our study of the community from that of its environment, we should be viewing all human action in terms of socionatural relations. If this paper contributes anything at all to that urgent goal, it has served its purpose.

Notes

1. This paper reports on work that is part of contracts EV5V-91-0021, EV5V-CT94-0486, and ENV4-CT95-0159 between a consortium of European research institutions, coordinated by the author for the University of Cambridge and for DG XII of the European Union, in the framework of the EU's Environment III and Environment IV programmes. We are especially grateful to Dr. P. Balabanis and Dr. D. Peter for their trust and encouragement.

2. For a more extended review of these issues, see the synthesis of the project published by the Publications Office of the European Union in 1998 (van der Leeuw 1998).

3. In ecology, this fundamental change in perspective is associated with the introduction of the concept of resilience, the ability of a system to maintain its structure in the face of disturbance and to absorb and utilize change (Holling 1973, 1986).

4. Perhaps it is wise to underline here that I do not of course maintain that other animals do not share these characteristics. As I write, ethologists are increasingly showing us examples to the contrary, and in view of the fact that this is no small part due to the fact that they are shifting their theoretical perspective, one may well expect more similarities to be brought to light soon. But it seems sufficient for my argument here to say that there (still) appears to be an important quantitative difference in both these respects between most animals and human beings.

5. Much the same thing occurs when a new scientific paradigm is discovered. Initially it is thought to be a remedy for all problems, and it is applied to a host of different questions. Only with time does the researcher find out for which kinds of questions the paradigm is really suitable and for which it is not (e.g., Kuhn 1962).

6. In other words, it can no longer dissipate sufficient entropy to survive.

7. In my view, it is this dynamic that is responsible for Hardin's "unexpected consequences" (1968).

8. This reversal is a fundamental constituent of our present world. In order to achieve it, humans reduce the environmental dynamic in many places to a much simpler set of rhythms and/or uncouple food webs spatially. As a result, the symbiotic system has become less stable in the classic ecological sense (diversity has been reduced), but it has gained in resilience and now survives through more rapid adaptation.

9. In this context, it is interesting to remark that large-scale degradation in much of the Mediterranean Basin is in fact due to the abandonment by the population of highly disturbance-dependent socionatural systems.

10. Ultimately, this need to differentiate may be a contributing positive feedback to acceleration of the growth of the cognitive sphere and the process of disembedding

at the cognitive and social levels, driving the separation between hierarchical and heterarchical systems even further.

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